New **IC**T infrastructure and reference architecture to support **O**perations in future PI Logistics **NET**works

D2.18 Mixed Digital/Physical Simulation Models for PI Networks Final

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Glossary of terms and abbreviations used

Abbreviation / Term	Description
CSE	Cloud Simulation Environment
DES	Discrete Event Simulation
GA	Grant Agreement
GPICS	Generic Physical Internet Case Study
GPS	Global Positioning System
KPI	Key Performance Indicator
LL	Living Lab
LSP	Logistic Service Provider
MABS	Multi Agent Based Modelling
MAS	Multi Agent Simulation
PI	Physical Internet
SCN	SELIS Community Node

1 Executive Summary

The key objective of this deliverable is to develop the digital and physical simulation models necessary to assess different scenarios with central focus on the evaluation and design of the Generic Physical Internet Case Study (GPICS) simulation components. The components are designed to be generic enough to ensure that the Generic Physical Internet scenario can be fully represented, taking also into account the specific requirements of the Living Labs.

This document explains the methodology of analysis of the business cases examined, through simulation, based on the approach identified by Law and Kelton [1], which outlined a framework where the main steps are defined as (a) designing and developing a simulation model, (b) designing a simulation experiment, and finally (c) performing simulation analysis.

In the previous versions of this document (D2.15, D2.16, D2.17) we primarily focused on the simulation model activities. In order to design the models, multiple face-to-face and virtual meetings were held, to determine the specific requirements of each of the living labs in the context development of Physical Internet (PI) for logistics and supply chains.

This fourth and final version of the document is focused on the development of the physical simulation model developed and designed to be integrated with the PI services. According to the iterative methodology defined, each simulation model begins with the description of the model with clarification of the assumptions made, and refined through the progressive addition of real constraints included in subsequent iterations.

The simulation scenarios are evaluated through the application of the defined key performance indicators. The simulation model allows for an evaluation of key operational criteria such as transport fill rate and lead-time and estimation of both direct costs (e.g. transport and handling), and indirect costs (such as CO_2 emissions).

Simulation models also make extensive use of real data obtained through the living labs (each a demonstration of application). The living labs are based on the real-world logistics processes of participating companies, and aim to execute the movement of goods according to the Physical Internet principles. The results of the simulation models applied to real cases will be shown in the corresponding Living Labs deliverables in the final reports of Work Package 3, at the end of the project.

The Physical/ Digital simulation models have enhanced the representation of the behaviour and interrelationship of various elements and factors necessary to test and validate the PI concept from a more realistic, day-to-day, point of view in each and every living lab. The simulation work is the very testing bed of the ICONET project and the framework through which PI concepts will be validated by the stakeholders.

2 Introduction

Digital Internet provides the best-known examples of interconnected networks, but there are others such as the evolving electric grid. Fundamentally, the Internet is the interconnection of computer networks in a way transparent for the end user. This allows the transmission of data packets in the form of standardized formats (datagrams) through heterogeneous equipment.

The Physical Internet (PI) [2] proposes a new logistics and transport model. It proposes to explore the impact of transforming the currently dissociated logistic services networks, with no coherence between them, to open logistics networks facilitating universal interconnectivity. The idea behind the mixed Digital/Physical simulation approach is that from a technical point of view, the models should allow the inclusion of information from both digital elements and physical sources. The use of simulation as a support tool in decision-making has grown in recent decades and is currently recognized as one of the most widely used research techniques for many sectors due to its versatility, flexibility and analysis potential.

In this project, to validate the impact of the PI approach in the Living Labs, as well as in the Generic PI Case Study, we primarily utilize discrete event simulation (DES) and multi-agent simulation (MAS). Simulations will be used to estimate the performance of the entire network associated with different routing policies and dynamic routing decisions, to identify optimal networks for collaborating centres, and to evaluate the efficiency of the PI-enabled services (e.g. Warehousing as a Service).

Deliverable "Mixed Digital/Physical Simulation Models for PI Networks" is one within the sequence of versions that have been submitted in months M7, M11, M18, and current one in M25. This document, D2.18, is the fourth and final release of this series of evolutionary documents.

2.1 Deliverable Overview and Report Structure

This document is divided into 8 chapters.

- The first chapter contains the executive summary, summarizing document purpose.
- The second chapter addresses in further detail the relationship between the content of the document and ICONET's contractual objectives.
- The third chapter describes the generic simulation model created to evaluate the impact of PI and the main components and their characteristics are defined.
- The fourth chapter describes the methodology that will be used to create regulatory models and then evaluate the scenarios with the developed models.
- The fifth chapter refers to the specific simulations that the project will carry out. First generic simulation of GPICS and living labs, in this version special focus in LL3 (e-Commerce centric PI Network) and LL4 (Warehousing as a service).
- The sixth chapter refers to physical simulations. These simulations are based on digital models and they are connected to the real ICONET services of physical processes.
- The seventh chapter includes the conclusions of the document.
- Finally, the eighth chapter contains the bibliographic references used in the document.

3 Simulation framework

This chapter deals with the definition of a digital simulation model that allows the virtual evaluation of the impact that the physical Internet application has on different supply chain scenarios. First, the necessary components are defined to create a digital simulation model. Afterwards, these elements are used to create digital models that represent the behaviour of the LL and the GPICS.

There are several methods to study a system. One of the most popular is made by Law and Kelton [1]. They classify these methods as shown in the following image (Figure 1) in two main groups; experimenting with the current system, and experimenting with a system model that contains physical and mathematical models. Physical models are useful to study the key mechanical properties or engineering aspects of a complex system. In the PI framework, the most relevant information generated in the physical world is the time (so record of progress to schedule or delivery promise) and position of the different containers, transports and other elements within the network. But the vast majority of the PI-related models are mathematical, representing a system as a set of defined logical and quantitative relationships that can be manipulated and changed to understand how the model reacts, and thus how the system itself would react. Once we have built a mathematical model (Figure 1), it can then be examined to see how it can be used to answer the questions of interest the system it is supposed to represent. If the model is simple enough, it may be possible to work with its relationships and quantities to obtain an exact analytical solution. But some analytical solutions can be extraordinarily complex, and require vast computing resources; inverting a large non-dispersed matrix is a well-known example of a situation in which there is an analytical formula known in principle, but obtaining it numerically in a given case is far from trivial. In this case, the model must be studied by simulation that is, numerically exercising the model for the inputs in question to see how output performance measures affect them. Simulation models are an abstract representation of reality with limitations and hypotheses in order to assess the impact of the features to be evaluated.

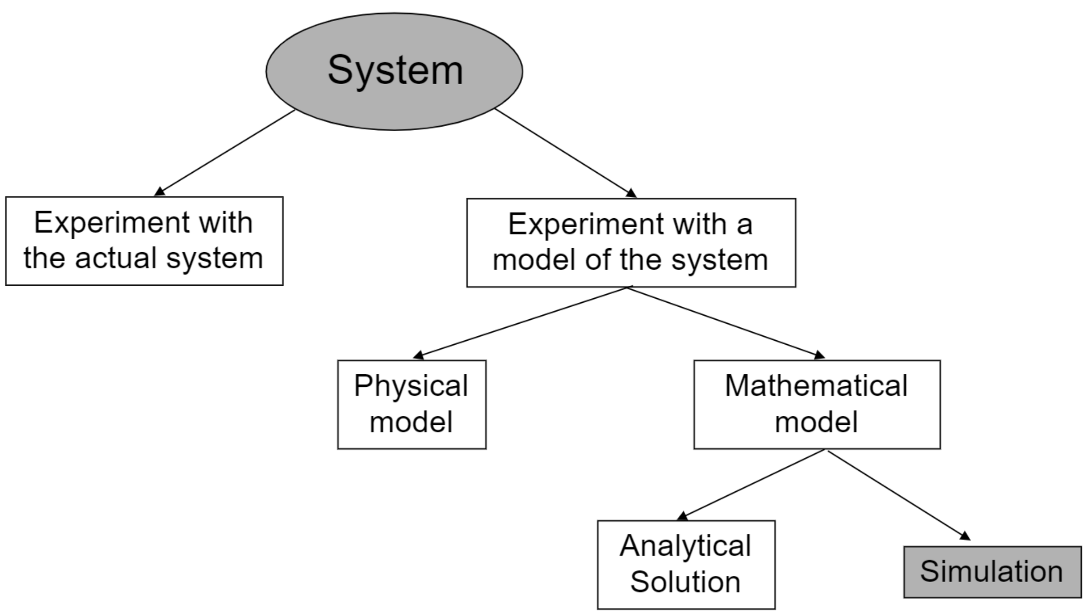


Figure 1: Methods to evaluate a system, Law and Kelton [1].

A static simulation model is a representation of a system at a particular time or one that can be used to represent a system in which time plays no role; examples of static simulations are Monte Carlo models [1]. On the other hand, a dynamic simulation model represents a customized system that evolves over time, such as transport system in a factory or a transport network. In the case of the physical Internet, the evolution of time is important, a flow decision taken at the beginning of the day may not be desirable four hours later, due to congestion or some delay in transportation. The dynamics of the system and the connection with real data are very important to determine the behaviour of the system. The mixed digital/physical simulation models connect the analytical power of the dynamic simulation with the physical information from the real system.

3.1 Mixed Digital/Physical Simulation Environment

Behind the idea of the mixed Digital/Physical simulation approach is the technical perspective, that the developed models should allow the inclusion of information from both digital elements as well as and physical sources. In certain simulation models, the information of some components (i.e. the position of a truck, or the storage capacity of one facility) could be obtained from a real physical entity, through APIs available in the cloud.

As mentioned [1] although there are few firm rules on how the modelling process should be approached, one point on which most authors agree is that it is always a good practice to start with a model that is only moderately detailed, which can later become more sophisticated if necessary. Robertson explains [3] that a model must contain sufficient detail to only capture the essence of the system for the purposes for which the model is designed; it is not necessary to have a one-to-one correspondence between the elements of the model and elements of the system. A model with excessive detail may be too expensive to program and execute. As is shown in the next image (Figure 2) the model proposes to increase the complexity iteratively. The first model contains many assumptions. Afterward adding real constraints, reducing the assumptions and the model becomes more realistic.

[1] *Monte Carlo methods (or Monte Carlo experiments) are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. Their essential idea is using randomness to solve problems that might be deterministic in principle.*

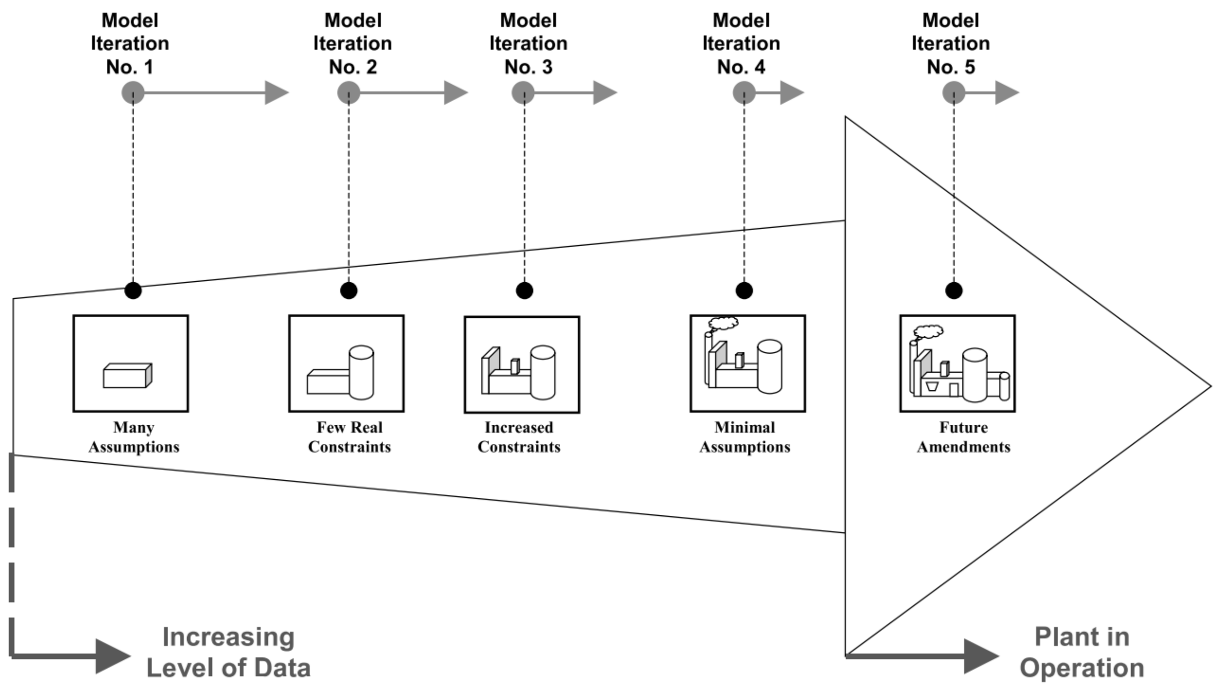


Figure 2: The iterative model building process, Robertson [4].

3.2 Digital Simulation components

The main objective of this simulation is to represent the PI network. In general terms, the network flow model consists of nodes and arcs. For modelling purposes, it is often convenient to assign names to the nodes. The arcs are directed by line segments. The nodes at their ends identify an arc. The arc passes from its origin node to its terminal node. In the PI context, there are different representations of network topologies such as [2] that is shown in the following image (Figure 3).

Network	Internet	Physical Internet	Interconnection function
Flow	Datagram	π-Container	Encapsulation of merchandise
Node	Router	Hub	Place of orientation (sorting), change of mode, service provider.
	Host (unique address)	Supplier or consumer	Place of containerisation and de-containerisation
Arc	Wire or wave connection	Transport services	Punctual or regular transport between two nodes.

Figure 3: Analogy between digital networks and physical networks. Montreuil, Ballot and Fontane [5].

In the simulation environment, global representation is done through agents. Agents can represent very diverse things: vehicles, units of equipment, projects, products, people in different roles, etc. The agents are the main components of the simulation model. The agent is a component of the design of the model design that can have behaviour, memory (history), timing, contacts, etc. The agent internal state and behaviour of the agent can be implemented in several ways. The state of the agent can be represented by a series of variables, by the status of the state graph, etc. The behaviour can be, roughly speaking, passive (e.g. there are agents that only react to the arrival of messages), or active, when the agent´s internal dynamics (waiting times or system dynamics processes) causes it to act.

A digital simulation model allows creating a representation of the physical world and its behaviour in a computer (Figure 4). The simulation model is dynamic. This means that it evolves over time. The rules of behaviour included in the model refer to changes in the temporal states of the processes and the participating elements. For example, when a truck arrives at a warehouse, its contents can be transferred to the stock of the warehouse, and a delivery notification could be sent to the sender or the recipient. The programmed dynamic rules are responsible for defining the quantity and time used in each of these processes.

Figure 4: General view of the initial version of the digital simulation model.

3.2.1 GPICS Roles

In the PI network, there are different actors involved. These players may have different roles, depending on the activity they perform on the network, as follows:

3.2.1.1 Sender

This role refers to the person (or company) that initiates the flow, the movement of goods through the network. This role has the initial information about the destination of the products and the delivery time interval.

3.2.1.2 Receiver

The receiver is the person or entity where the flow ends. The receiver indicates the allowed interval for the delivery time (delivery time window). This role could have access to the tracking system to be informed about the estimated arrival time.

3.2.1.3 Transport & Logistics Service Provider

This is one of the most important roles in the PI framework. This role has the responsibility of moving containers through the network and also of carrying out the handling operations with the containers. In the PI framework, traditional transport companies, single mode transport (e.g., road, train, or ship) could coexist with intermodal companies. Intermodal freight transport involves the transport of cargo in an intermodal container or vehicle, using multiple modes of transport (e.g., rail, ship, and truck), without any handling of the cargo itself when changing modes.

Logistics service providers (also known as Third-party logistics providers) specialize in integrated operation, storage, and transport services that can be scaled and customized to the needs of customers based on market conditions, such as the demands and requirements of the delivery service of their products and materials.

3.2.1.4 Coordinator

In [6] there is a description of some communication and decision capabilities needed to be executed by PI containers or coordinators. For example, a decision-making capacity: PI-containers should be able to make some decisions autonomously; including ultimately determining the optimal transport route from an origin to destination at the network level, or optimizing movements of sorting and classification at PI-hub level. Communication capabilities: these capabilities are important for traceability and condition monitoring issues.

In the simulation model, all these capabilities are focused on the Coordinator Agent. This agent can have an overview of the state of the system and provides answers to critical decisions of other agents (such as containers or transports). Some of these decisions can be automated by the use of external services which have information from different parts of the system.

3.2.2 GPICS Container

The "container" is a key element of the physical Internet and, therefore, a large amount of research and design work must be done to define it and to adjust the "movers" and the treatment in "nodes". The container is fundamental for the physical Internet, it is the metaphor of the Digital Internet [7]. By analogy with data packets, the goods are encapsulated in intelligent containers of easy-to-interconnect modular dimensions, called PI-containers, designed to flow efficiently in hyperconnected networks of logistics services The ubiquitous use of PI-containers is to enable any logistics service provider to handle and store the products of any company as it does not handle or store the products by itself. The GPICS container concept is not only limited to the special modular containers described in projects like Modulushca [8] which was tasked with "developing a vision addressing the user needs for interconnected logistics in the FMCG domain, the development of a set of exchangeable (ISO) modular logistics units providing a building block of smaller units, establishing digital interconnectivity of the units [2]". The PI specific modular container helps the PI operations, but another type of container, like euro-pallet or semi-pallet, are possible at the early stages of the PI network design. The GPICS container is mainly focused on existing container types but with smart capabilities.

The PI container is the load reference unit for moving products within the PI network. From the perspective of simulation, it is an especial agent that can be transported, handled or delivered. The main information that is needed in the simulation model to move a container through the network is represented in the following table (Table 1).

Table 1: Main attributes from a GPICS Container.

	PI Container (v.1.2)
idContainer	Unique identifier of the PI-container through the Physical Internet
idOrigin	Unique identifier of origin node in the PI network
idDestination	Unique identifier of the destination node in the PI network
idSender	Unique identifier of the sender of the container. The initial owner of the products.
idReceiver	Unique identifier of the receiver of the container.
deliveryTimeMax	maximum delivery time
deliveryTimeMin	minimum delivery time
GPSLatitude	Latitude GPS coordinates

[2] https://egvi.eu/research-project/modulushca/

GPSLongitude	Longitude GPS coordinates

In addition, to manage the flow of the container within the simulation model, some special attributes have been defined:

- NextNode: The actual next node planned for container movement.
- NextTransport: The actual next transport planned to move the container.
- ActualStatus: The actual status of the container.
  - S00: Created
  - S01: IdContainer assigned
  - S10 Waiting for an order
  - S20 Waiting for transport
  - S30 In Transit
  - S90 Delivered to receiver

Some of these attributes are defined as they are detected in the evolution of the simulation. In the following image (Figure 5) we can see the properties of a container type agent. The main attributes (idContainer, idOrder) and auxiliary variables such as the product type (if A, B or C is written), the identifier of the transport that moves the container, the identifier of the node that contains it, the list of nodes through which it has passed (list_nodes) or the transports it has used to move (list_transporters)

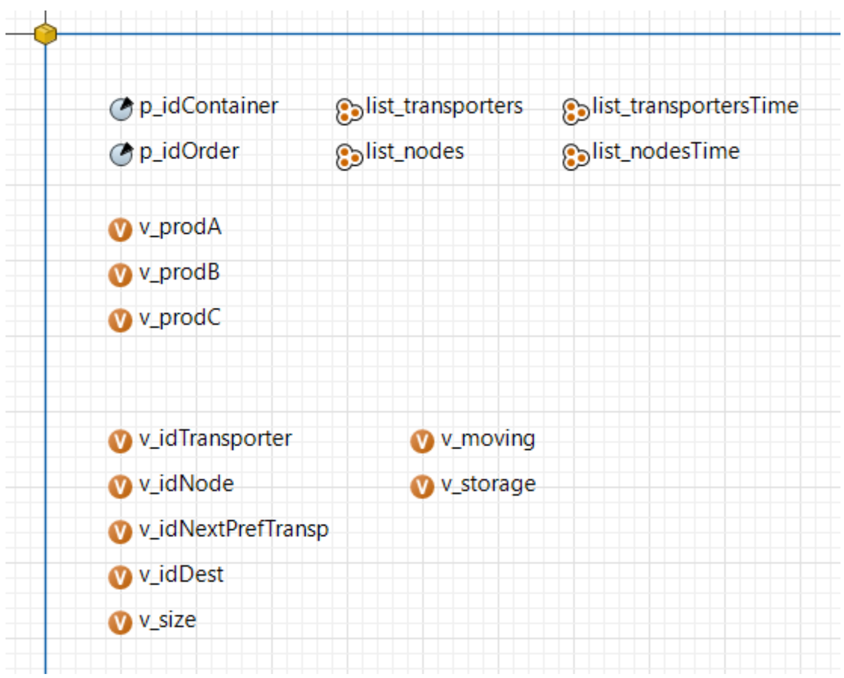


Figure 5: Initial representation of the GPICS Container properties in the digital simulation.

As mentioned in the article "Towards a Physical Internet" [9] the container system in the Physical Internet is not a closed system. Therefore, a container could be in a current container ship and/or could even contain pallets.

3.2.3 GPICS Mover

The elements "GPICS Mover" are responsible for the transport actions in the PI network. The transporters, convey or handle containers within and between the nodes of the Physical Internet. The GPICS transporter has some basic attributes that are shown in the following table.

Table 2: Main attributes from a GPICS Mover.

	PI Container (v.1.2)
idMover	Unique identifier of the GPICS-mover through the Physical Internet
typeMover	Identification of type of transport: truck, train, van…
idPath	Unique identifier of path followed by the mover. (Through the links between the nodes)
typeFrec	Identification of the type of frequency of the transport: Daily, Weekly, Non-Stop, OnlyOneTrip, etc.
attCapacity	Attribute to indicate the capacity of the transport
attFillingRate	Attribute to indicate the filling rate of the transport

In addition, in order to manage the behaviour of the different mover within the simulation model, some special attributes have been defined:

- NextNode: The actual next node planned for GPICS Mover movement.
- ActualStatust: The actual status of the GPICS Mover.
- Status Diagram: This diagram shows all the possible status of the transport (idle, entering a Node, searching for destination…) and the logic conditions to evolve from one status to the next.

In the following image (Figure 6), there is a representation of the main attributes of a GPICS Mover Agent in the simulation model.

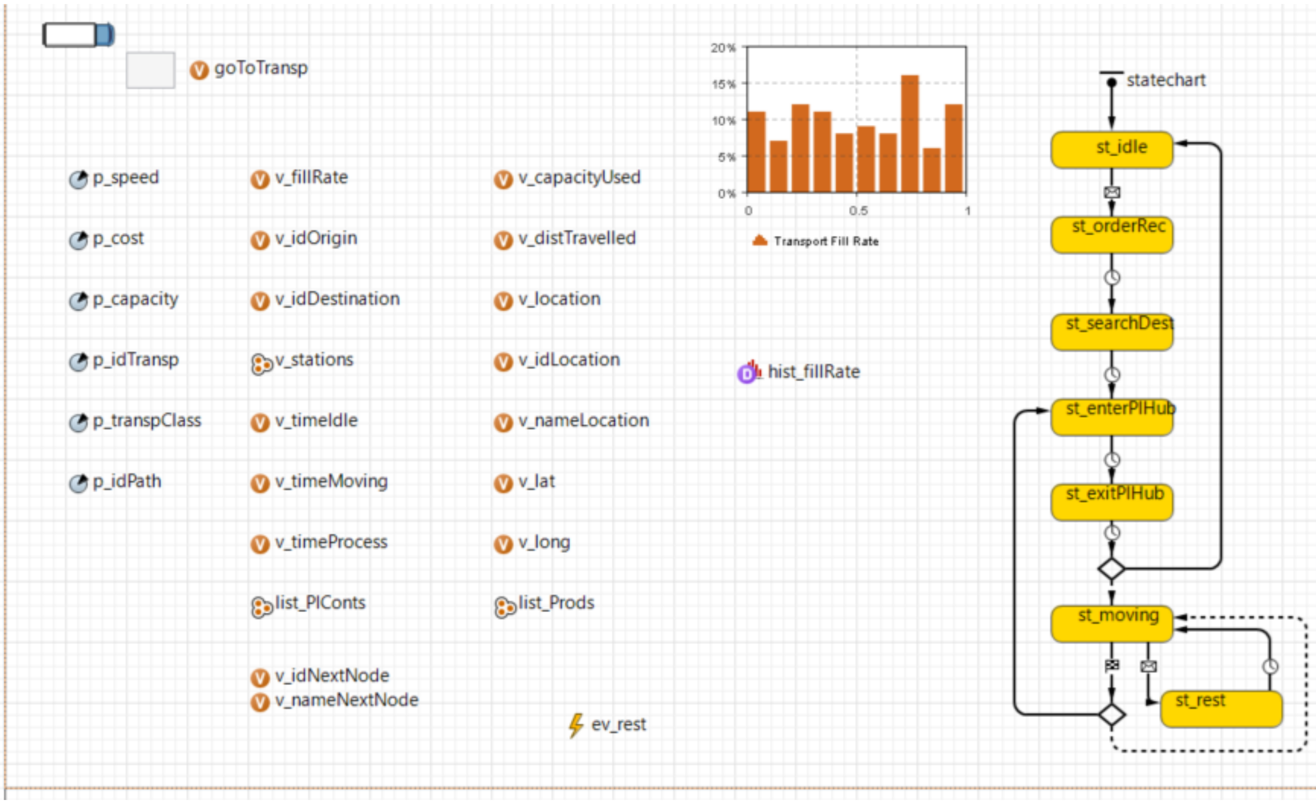


Figure 6: Initial representation of the GPICS Mover properties in the digital simulation.

3.2.4 GPICS Node

One of the key points developed in the ICONET project is the Generic Hub, as the main element of the Generic Physical Internet Case Study (GPICS). The Generic Hub represents a node in the PI network, where goods are stored, transferred or manipulated between movements. The GPICS node could also be called Generic Hub, is the main element to create the PI network. In the simulation context, the GPICS node has several functionalities to represent potentially different elements of the real PI (such as warehouse, ports, factories or intermodal terminals). The physical Internet consists of embedding a large number of nodes. These nodes include producers and consumers around the world.

Some of the main function of the GPICS node is defined in the following image (Figure 7) defined by Sarraj and Montreuill in [2].

Function	Digital Internet routers	Physical Internet π-hubs
Receiving	De framing and framing[4] according to the network protocols used	Unloading and/or decomposition of arriving π-containers
Routing	Transfer following a table	Selection of the next destination for each π-container
Shipment	Framing according to the selected network	Composition of π-containers and loading on transport means

Figure 7: Analogy between Digital Internet routers and Physical Internet Hubs. [2]

As described in [7] the activities to be carried out in a node can be of different types. Some of the main examples are shown in the following list:

- Transfer of containers from their inbound vehicles to their outbound vehicles Transferring multimodal containers on a one-to-one basis that does not involve multiplexing.
- Receiving containers from one or more entry points and ordering them to be sent from a specified exit point, potentially in a specified order.
- Storing containers during the target time windows.
- Receiving containers and releasing them so that they can be accessed and their content on a private network that is not part of the Physical Internet.
- Receiving containers from a private network and register them on the Physical Internet, directing them to their first destination along their journey through the Physical Internet.

With respect to the different ideas of the review of the literature, in the ICONET project, we have defined the following schema to simulate the generic operations within a GPICS node.

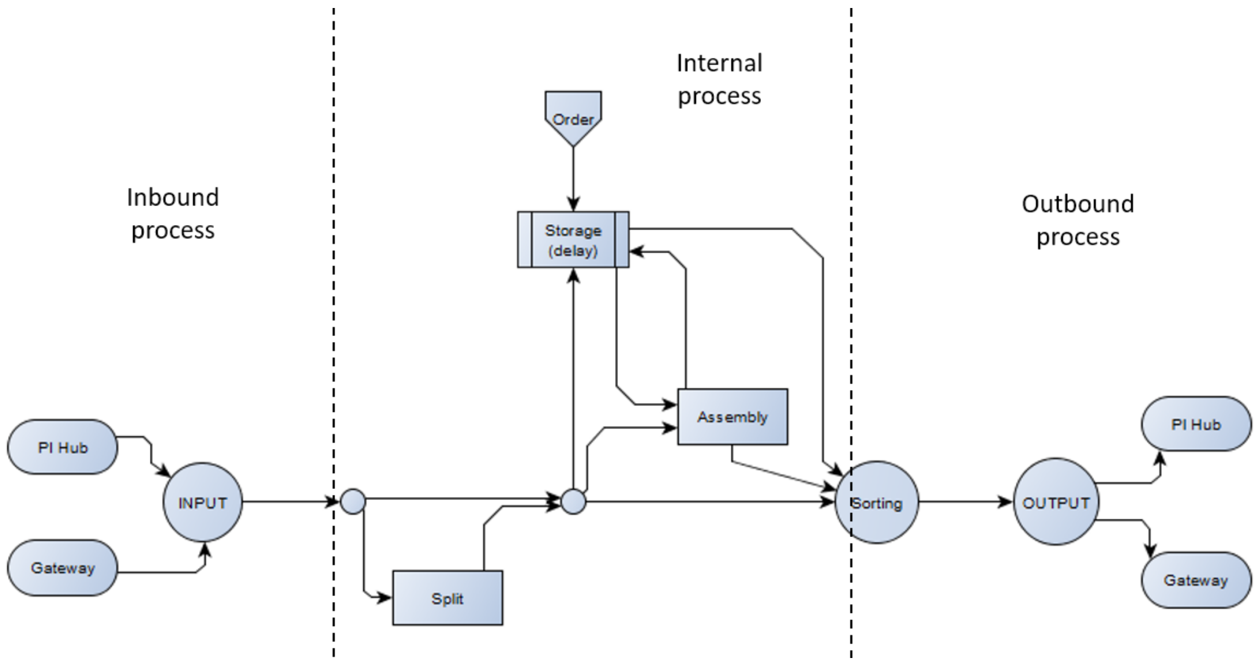


Figure 8: Generic schema of the main operations inside a GPIC node.

The diagram (Figure 8) shows the main functionalities of a generic node. In the material flow input, inbound process, two options are observed. The first one allows the entry of containers from the PI network. This type of container is already identified and does not need an additional reception process to identify the merchandise it contains. At this point, entry through a gateway element is also allowed. The gateway allows new containers to be introduced to the PI network from networks that are external to PI.

A validation and verification process physically equipped for the containers to enter the network complying with the digital physical conditions required by PI protocol. Next section represents the internal processes of the warehouse. There is a split operation. This module allows to separate the containers in different elements. For example, pallets from the same supplier in the different final destinations. Once the containers are separated, they can take three alternative routes, such as going to a storage area, or going to an assembly area, or directly to a sorting and shipping area as if it were a cross-coupling-flow.

In the storage area, the containers can wait a few days until the node receives an order with the output information of this material. It is common that, when leaving the storage area, there is an occupation of different products or towards the same final destination, for example, in the retail sale, the preparation of the material for a store is made up of the different products that need to be replaced in the supermarket. When the products are already prepared, the classification process is applied to group the containers that are directed towards the same destination.

Table 3: Main attributes from a GPICS Node

	PI Container (v.1.2)
idNode	Unique identifier of the GPICS-mover through the Physical Internet
typeNode	Identification of the type of transport: truck, train, van…
GPSLatitude	Latitude GPS coordinates
GPSLongitude	Longitude GPS coordinates
attCapacity	Attribute to indicate the capacity of the transport
attFillingRate	Attribute to indicate the filling rate of the transport

Throughout this physical process, different decisions must be made, for example, if it is necessary to separate the load from the receipt of a truck, how long a pallet should be stored, if it is necessary to group different pallets or what is the best transport to advance to the next destination. The following (Figure 9) supports the understanding of these decisions. In fact, this figure shows the schematic representation of a Generic Hub internal process. Starting from the left side, the flow begins with the reception of the products. Subsequently, there is a classification process, in which the decision is made as to whether the container should be separated or added, with other containers. There is also the possibility of temporary storage until a new order of movement for the products arrives. The lower part represents the state of the movers (i.e. trucks, trains). Initially, the movers perform the unloading of containers. Second, they can wait some time or, finally, they can load new products into the node, and continue to the next destination.

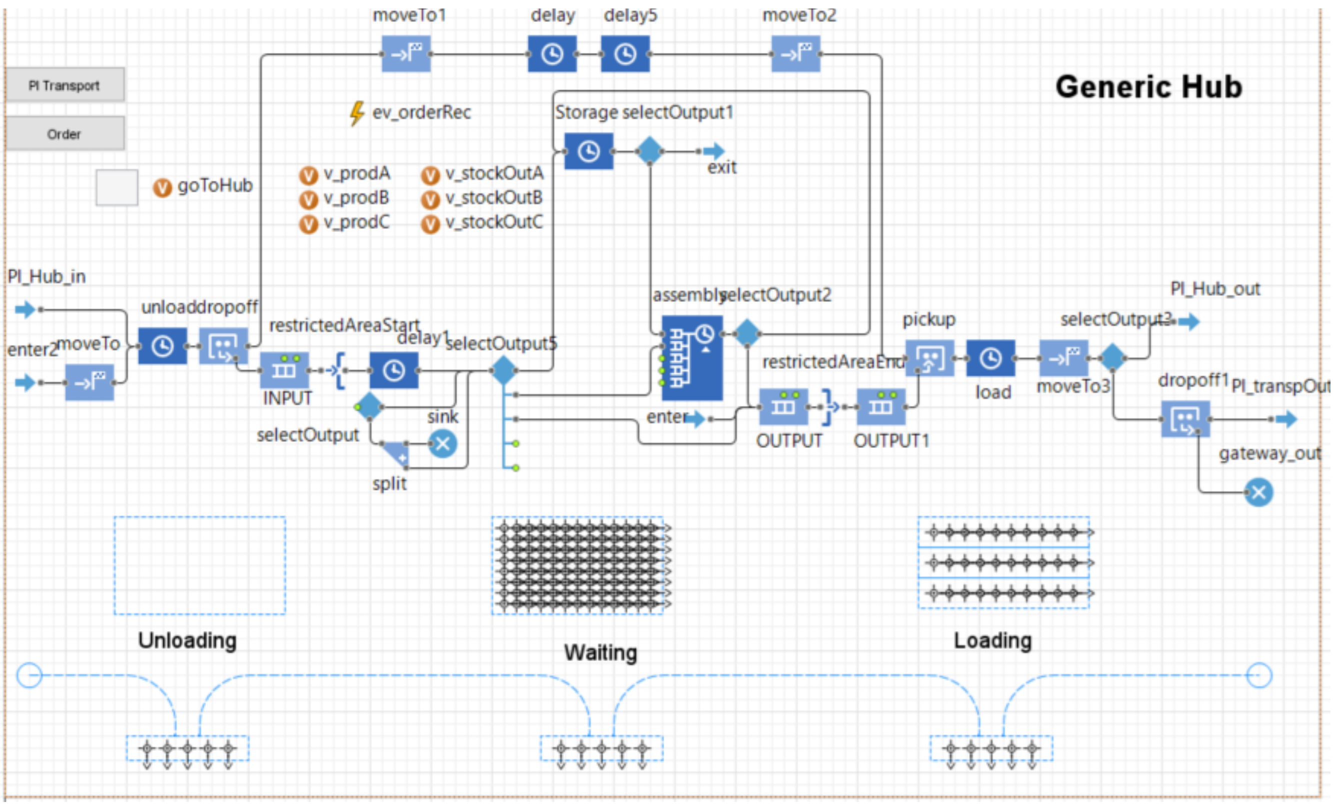


Figure 9: Generic schema of the simulation model of a GPIC node.

This node representation is very flexible. As mentioned in the ICONET GA, some hub topologies implemented under the SELIS project [10] can be adapted, and actual transport events can be provided by utilizing and integrating with the SELIS Community Node (SCN). All the principal SCN components have been identified and described under the WP4 (SELIS ICT Platform and Infrastructure) Deliverables of SELIS Project (GA No 690558).

3.2.5 GPIC Link / Corridor

The physical Internet is about networks of networks, each one integrates nodes and links between these nodes, with standard modular containers. The connections between the nodes used by the GPICS movers are called GPIC Link. The group of GPIC Links used by some movers to cover more than one node, in sequence, are called the GPIC Corridor. The main attributes of a GPICS link are listed in the Table below.

Table 4: Main attributes from a GPICS Link

	GPICS Link
idLink	Unique identifier of the GPICS-link in the Physical Internet
idNodeStart	Identifier of the initial node of the link
idNodeEnd	Identifier of the final node of the link
typeLink	Link type according to the selected transport mode (road, rails, sea…)
attCapacity	Attribute to indicate the capacity of the transport
attCongestion	An increment of the transit time due to external incidences
attTransitTime	Average trip duration from start to end of the link

The concept of the corridor is related to the group of links used by a transport (usually a truck or train) to go through several nodes. Some properties from the links, like the congestion, could be applied to the corridors included. The main attributes from a GPICS Corridor are listed in the Table below.

Table 5: Main attributes from a GPICS Corridor.

	GPICS Corridor
idCorridor	Unique identifier of the GPICS-corridor in the Physical Internet
listLinks	Set of Links included in the corridor

3.2.6 GPIC Order

Order is the element of information that causes products to move within PI. The order is associated with a set of containers, which must be transported from a point of origin to one (or several) destinations. The following table lists the main attributes related to GPIC order.

Table 6: Main attributes from a GPICS Order.

	GPIC Order
idOrder	Unique identifier of the GPICS-order in the Physical Internet
listContainers	Set of containers included in the order
idSender	Unique identifier of the sender of the order
idReceiver	Unique identifier of the receiver of the containers
deliveryTimeMax	maximum delivery time
deliveryTimeMin	minimum delivery time

3.3 Physical Simulation components

Within this project, the physical simulation is a tool for a better understanding of the PI processes that involve physical elements that handle goods (PI means). The physical simulation models are integrated with the real elements through the PI services presented in the following figure (Figure 10). The main services are the following: networking service, to define the connection of the supply network through PPI. Routing service to support best route decisions, where best route might be on the basis of costs, throughput or emissions, and also includes optimization that considers hub topology, network state, and cargo type. Shipping services deal with the management of the procedures and protocols for configuring the quality of service, monitoring, verifying (acknowledgment), adjourning, terminating and diversion of shipments in an end-to-end manner. Encapsulation services, identification and propose efficient encapsulation assignments of products within specific PI containers, considering existing and emerging standards for physical interoperability.

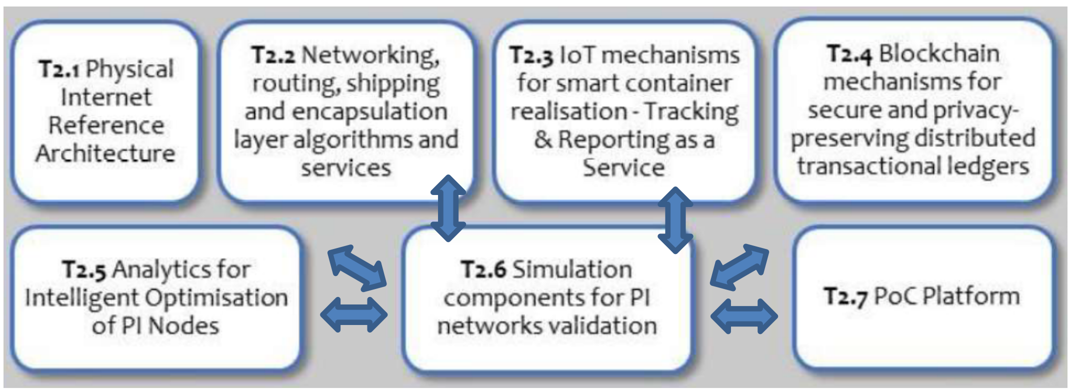


Figure 10: Simulation model interaction schema

3.3.1 Service integration description

The process simulation is integrated with the different ICONET services to interact with the real elements of the physical network. Through these services the simulation models are dynamically configured, the number and position of the nodes are defined, the dynamic route for the containers is calculated, the necessary container groupings are created and the best mode of transport is specified through the following services. (*Detailed description is contained within separate deliverable: D2.4 PI networking, routing, shipping and encapsulation layer algorithms and services*).

- *Networking*: Networking defines the interconnected infrastructure of available processing, storage and transporting facilities (transport services, terminals, distribution centres, warehouses) through which the goods will be transported from their origins (manufacturing, distribution and other locations) towards their customer(s) locations.
- *Routing*: Routing is a process that creates a plan that describes the stage by stage detailed visiting and usage of networking nodes from origin to destination.
- *Encapsulation*: How products to be shipped are encapsulated in modular packets that are then consolidated/deconsolidated into containers for transportation via the PI.
- *Shipping*: Shipping specifies what has to be transported and any constraints and restrictions about its transport.

The following image shows an example of how these services can interact. At the beginning of this diagram an order is created that will be served through the physical Internet. The order data is communicated between the different layers according to the NOLI model, in order to calculate the number of nodes, the best route and also with the IoT platform to locate where the container is at any moment.

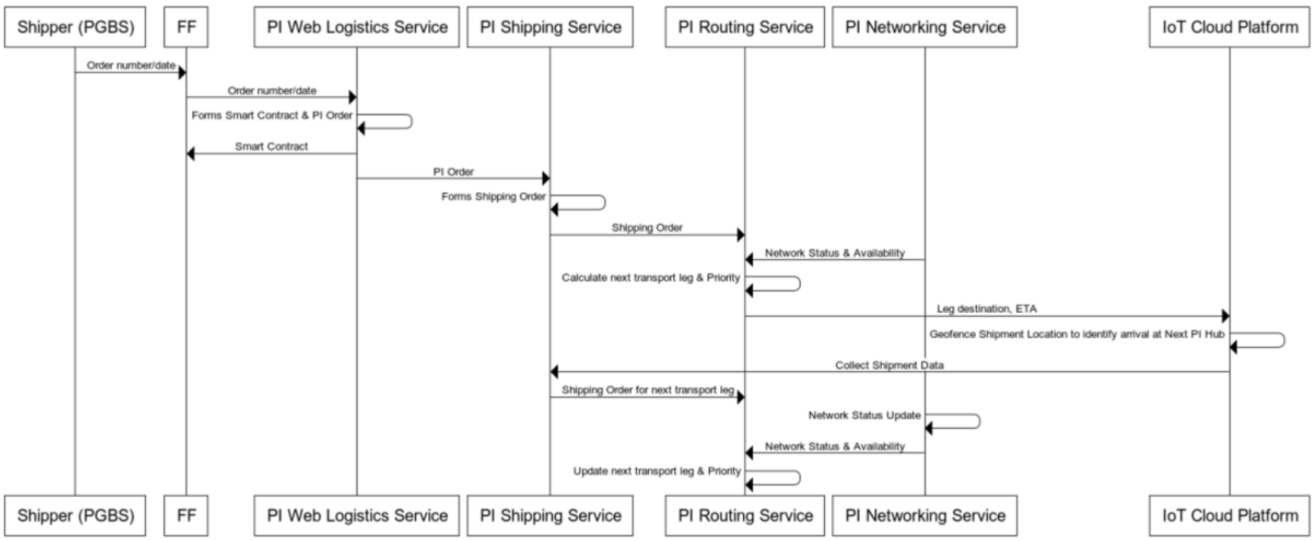


Figure 11: Service interaction schema

4 Methodology for Calculations

The use of simulation as an aid in decision-making has grown in recent decades. It is already used as one of the most used research techniques for many sectors due to its versatility, flexibility and analysis potential. The article "A multi simulation approach to develop Physical Internet" [11] describes how the use of different types of analytical models and simulation tools could help to create trust confidence around the PI concept. The simulations help to analyse business models, evaluate the relationship between the main variables, visualize the flows, understand the dynamics of the processes, and finally, quantify the impact.

The calculation methodology used is the same as in previous versions of this deliverable. Please review chapter 4 of Document D2.17 for further details.

4.1 Scenario definition

One of the main objectives of this task is to develop and compare the impact of PI in different scenarios. The scenarios are defined by a simulation model, a group of orders (or movements to evaluate) and a set of options which determine the behaviour of the model in the scenario as it is shown in the following image (Figure 12).

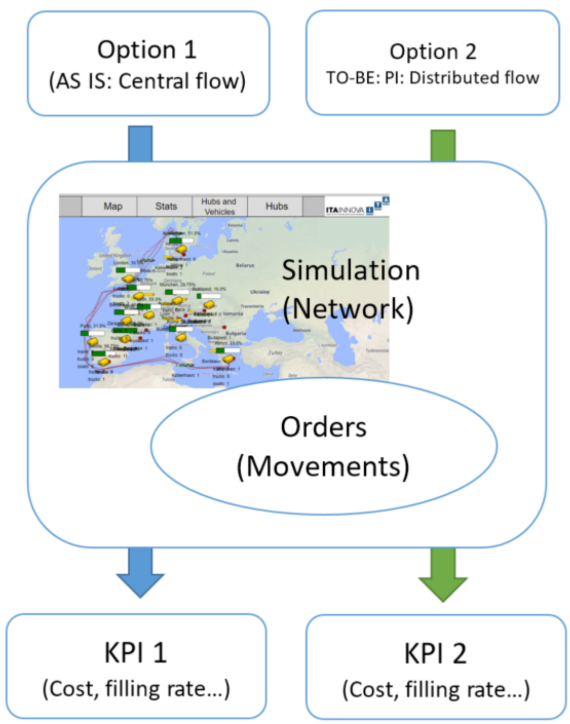


Figure 12: Schema for scenario definition.

The main elements that determine one scenario are:

- Simulation model: Contains the code for representing the behaviour from the main elements in the PI framework: PI Hubs, PI corridors, PI Coordinator (services: routing, composer etc.). The simulation contains also the network configuration for the scenario.

- Orders: The order is the set of movement of elements (mainly PI containers) that circulates through the model. Movements are made by the transport service provider, from sender to receiver and controlled by the PI coordinator.
- Options: The options are the configuration parameters to define a specific scenario (AS-IS, TO-BE…).

5 PI Business Cases digital simulation

In ICONET project, emphasis will be given to the simulation modelling of the PI network of the generic case study (GPICS) together with each Living Lab Use Cases, considering different types of elements (factories, distribution centres, urban hubs, point of sales, etc.) and its specific characteristics (geographic locations, capacity, performance, etc.). Subsequently, the simulation model will be used to evaluate different business cases such as the Generic Hubs Plan and the scenarios proposed in the living labs. The main objective of these business cases is:

- **LL1 - PI Hub-centric Network**: The objective of this model is to evaluate the capabilities of different hub types and the possible connections to support optimized PI networks in which PI containers travel according to synchromodality principles. This living lab includes movements between nodes: from a terminal to terminal, within a PI hub, from a terminal in one PI hub to a terminal in another PI hub; between PI nodes (warehouses, distribution centres etc.) in a PI corridor.
- **LL2 - Corridor-centric PI Network:** The focus of this LL examines the transformation (modelling) of TEN-T corridors into IoT-enabled PI corridors, to support optimized movement of PI containers between two PI hubs and the broader PI network.
- **LL3 - e-Commerce centric PI Network:** This LL explores the impact of the PI on e-commerce fulfilment models. Last-mile transport is an important aspect of the overall PI landscape. Redesigning last-mile distribution centres to fulfil PI hub roles and investigating the role of other forms of mobile or multirole last-mile hubs fall within this scope.
- **LL4 - Warehousing as a Service:** With this model, we pretend to investigate the role of the warehouse as a key PI node acting as a dynamic buffer for flow between other PI hubs, so as to increase the throughput of hubs, reduce congestion, etc.

All the living labs have some connection between the physical elements and the digital interactions. But, we are going to create two groups to evaluate with higher detail the influence of the digital aspects and the physical elements of the PI framework. The first two Living Lab (LL1, LL2) put the focus in the physical movements of the container in a maritime hub and in the corridors. The last two living labs put the focus in some digital services around the PI framework, the eCommerce distribution network and the warehouse as a service. In this chapter, we are going to evaluate LL3, LL4 and the GPICs through the digital simulation. Chapter 5 contains the mixed physical simulation from Living Labs 1 and 2.

In addition to the Living Lab simulations model, a generic PI Case Study simulation is conducted to generate wide scope model. The GPICS model was described in the previous version of this document D2.16. The description of this model is included in the Annex 1 of this document.

5.1 Simulation LL3 e-Commerce centric PI Network

The simulation of the LL3 is focused in the evaluation of the efficiency of the PI concepts in an eCommerce distribution network. In particular it compares multiple locations (stores and warehouses) to assess best option to fulfil an order in terms of cost, lead time and stock out, considering different distribution networks, from different companies.

5.1.1 Objective

The main objective of this Living Lab is to measure the impact of the PI framework in two important areas of the e-Commerce distribution network: the fulfilment process and the operational cost.

- Fulfilment: e-commerce orders suffer from many stock-outs as products might not be available for delivery from the central warehouses/stores. On these occasions, the picker is instructed to choose a similar product by quality and price, which is a subjective process lacking efficiency. This also exposes the business to a (small) risk of not acceptance of the replacement - while the products might be available in other stores which are not subject to picking option.
- Costs: The cost of picking and delivering an order still remains high and not competitive in the current business context, particularly exacerbated by returns costs. An optimised, PI-inspired, decentralised model could potentially provide an alternative for near-to-consumer fulfilment, reducing costs, lead-time and emissions.

The specific objectives are to evaluate different parameters from the network performance like:

- Improve service level for customers: Lead time and stock-out reduction.
- Evaluate best time windows to offer in the different delivery regions (in order to facilitate more effective and efficient delivery operations).
- Design an efficient network, using networks from different companies, of pickup-points conveniently located for the customers.

5.1.2 Simulation model

Classic supply chain design relies on a hierarchical organization to store and distribute products over a given geographical area. Inventory management is an important chapter of Supply Chain Management because it plays a key role in the performance of supply chains. In the Fast-Moving Consumer Goods (FMCG) sector, inventory costs generally represent up to 40% of the total logistical costs (Cachon & Terwiesch, 2006), not to mention the cost of shortages in retail shops, i.e., approximately 7% of products in the supermarket.

5.1.2.1 Simulation Elements

The principal elements of this LL, according to the Generic PI Case Study framework are:

- PI Nodes
    - Central Warehouse (dark-store)
    - Support store
    - Stores (Click and collect)
    - 3rd party stores
- PI Corridors
    - Truck (inter-city)
    - Delivery van (urban area)

- PI Roles
  - Sender
    - Sonae
  - Receiver
    - Client at home
    - Client at store
      - Inner store
      - Pick-up point
  - Transport
    - Delivery van (urban area)
    - Urban electric vehicle: Last mile (GLOVOS)
  - Coordinator
    - Sonae

5.1.2.2 *Input data*

This living lab is focused on the eCommerce distribution network for the retail sector. According to the input data structure defined in the respective section of this document, the information required contains the nodes, the links to define the network, the routes from the transports in the network, the characteristics from the transports and finally the orders from the customers with the quantities and the references. In the following images there is a short description of the tables and some data examples.

Table Name	tbl_00_Nodes
Description	Description and geolocation of the nodes of the network

index	idLivingLab	idNode	desNodeName	NodeLevel	Lat	Long	Country	att1
0	0	0	Madrid	1	40	1	Spain	
1	0	1	Paris	1	40	1	France	
2	0	2	Bourdeaux	1	40	1	France	
3	3	101	Entreposto	1	41.234889	-8.639159	Portugal	Warehouse
4	3	102	CDP	1	39.251022	-8.710778	Portugal	Warehouse
5	3	103	CPC	1	39.256333	-8.714278	Portugal	Warehouse
6	3	201	Continente Bom Dia Via Ráp	2	41.1765359	-8.647649	Portugal	Store
7	3	202	Continente Bom Dia Espinh	2	41.00061568	-8.638717	Portugal	Store

Table Nodes: Description of the location of the nodes and main attributes.

Table Name	tbl_10_Links
Description	Description of node conections (links) available in the network

idLink	idNode1	idNode	Node1	Node2	Tr
11012201	101	201	Entreposto	Continente Bom Dia Via Rápida	
11012202	101	202	Entreposto	Continente Bom Dia Espinho	
11022201	102	201	CDP	Continente Bom Dia Via Rápida	
11022202	102	202	CDP	Continente Bom Dia Espinho	
11032201	103	201	CPC	Continente Bom Dia Via Rápida	
12012401	201	401	Continente Bom	VNG - Ameal	
12012402	201	402	Continente Bom	VNG - Arcozelo	

Table Links:

Connection between nodes available in the network.

Table Name	tbl_11_RelRouteNodes
Description	Relationship between nodes to create routes

idRel_route_	idRoute	routeOrder	idNodeNo	DesNode
1456	1	0	101	Entreposto
1457	1	1	201	Continente Bom Dia Via Rápida (Port
1458	1	2	401	VNG - Ameal
1459	2	0	101	Entreposto
1460	2	1	202	Continente Bom Dia Espinho
1461	2	2	401	VNG - Ameal

Table Route Nodes:

Configuration of routes between different nodes.

Table Name	tbl_21_Transport
Description	Description of transport properties, route asignation, frecuency...

idTransport	idRoute	idHomeNode	Capacity [kg]	Regular	Frequency [days]	Cost [€/km]	tr
123	1	101	1500	1	1	0.8	
124	2	101	1500	1	1	0.8	
125	1	101	3000	1	1	1.2	

Table Transport:

Definition of the transport properties like capacity, frequency or cost.

Table Name	tbl_31_Orders
Description	Description of movement orders, origin, destination,qtty

idorder	idOrigin	idDestination	dayIniOrder	leadTimeDays	OrderLines	Weight	Fam1	Fam2	Fam3	Freq
0	101	201	1	1	5	99	100			7
1	102	201	1	1	5	99		100		7
2	103	201	1	1	5	99			100	7
3	201	401	2	1	5	3	2	2	1	1
4	201	402	2	1	10	6	3	3	4	1
5	201	203	2	1	15	9	6	6	3	1

Table Orders:

Information about the origin, destination, lead time available, the weight or the products to send trough the network.

Figure 13: Example of the input data for the simulation model.

In order to create a representative set of the clients and the orders, we have selected a group of clients from the Oporto network, shown in Figure 14 (Orange square sores, Blue cross client's postal codes). To facilitate the agility of the calculation, a representative sample of the entire distribution network has been taken. The selection of clients, products and stores has been carried out proportionally, so that the results obtained from these experiments could be extrapolated to the total network.

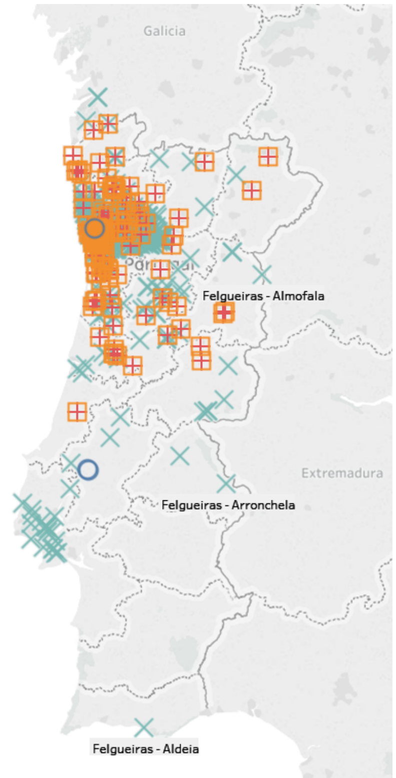


Figure 14: Geographical scope of the eCommerce network.

5.1.2.3 Main KPI

The main KPIs in this Living Lab are focused in evaluating the service level perceived for by the client and the Operations efficiency. The following KPIs quantify the anticipated improvements that SONAE expects to realise due through application of the ICONET solutions.

- Decrease total e-commerce stock holdings. Stock levels [5%]
- Shift of existing centralised sales to the new de-centralised model. Value of Sales [10%]
- Improve chain reliability, by decreasing the required product changes (with other equivalent products) in order fulfilments. Number of unexecuted items (orders) in SKUs [30%]
- Less stock-outs or product substitutions. Non-executed orders [25%]
- Decrease the average delivery lead time. Lead time [25%]
- Decrease total cost of order fulfilment. Cost value [10%]

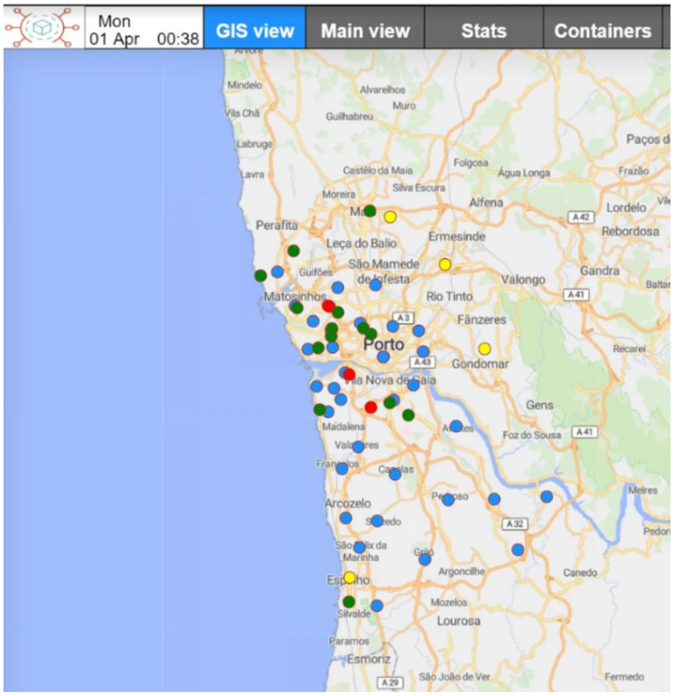
Using the digital simulation model, it is possible to estimate the value of some of these indicators. The definition of this KPI in the simulation model are:

- **Stock out cost:** when the model prepares an order, it gets the stock outs with the current node's stock and the quantities to be served in the order.
- **Order fulfilment cost**: "total cost of executing the order", this indicator takes the aggregate costs in the model. Included costs are: delivery cost and handling cost.
- **Delivery cost**: cost of the transport for the current order/PI container. Cost per order, accumulated with containers' steps (a container can be moved for several transporters when accomplishing an order). Transport activation cost + transport distance cost * trip distance
  - **Handling cost**: cost of preparing the order. Cost per order, accumulated with all the containers that are served because of it (i.e.: a weekly order will have containers serving each week). Handling cost = picker cost * preparing time.
- **C02 Emission**: Estimated C02 emission. The average rate considered for the transport in this Living Lab is 500 gr/km.

5.1.2.4 LL3 Sim V.2.1: Multi company network in Porto

Different simulation models have been made iteratively to evaluate the living lab 3 distribution network. The detailed description can be consulted in previous versions of this deliverable such as D2.17.

The objective of this version of the simulation model is to evaluate the effects of multi network urban distribution for ecommerce. Simulation of the potential benefits of joining networks distribution from different companies. The main company in this model is the Sonae network (warehouse, stores and distribution network). In this simulation model, in addition to the nodes of the Sonae Company, nodes from other companies are considered, such as Kasa or Wells, which are distribution companies, currently operating with totally independent distribution networks.



Store Location Sample

- Red: Darkstore
- Yellow: Big store
- Green: Medium store
- Blue: Final client location

Figure 15: LL3 network nodes distribution.

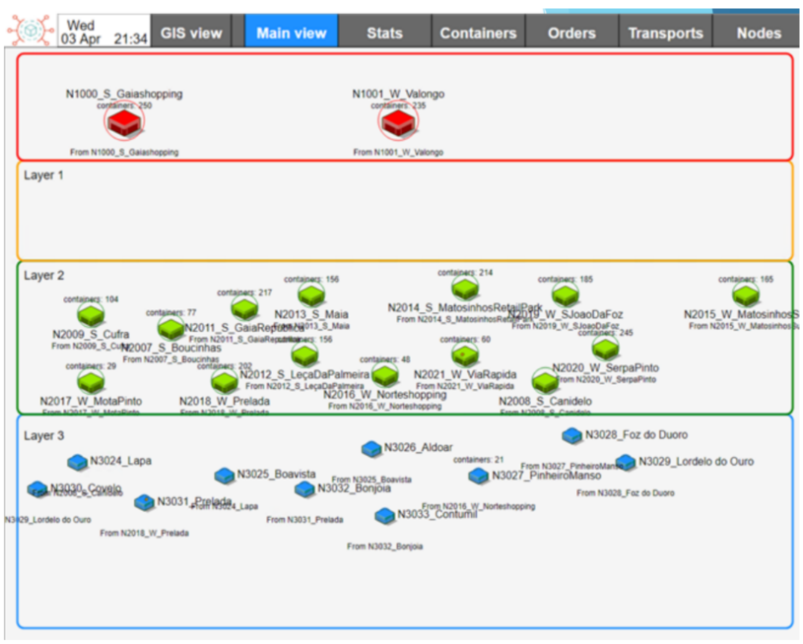


Figure 16: LL3 network nodes tree.

5.1.3 Simulation Scenarios

In this version of the deliverable, the main scenario is focused in the evaluation of the impact of the network configuration with multiple companies. The main analysis is the network configuration

Table 7: Brief description from each scenario in LL3.

	LL3 Scenario Description
321 - Independent network per company	In this scenario each company uses its own transports to supply stores and to fulfil e-Commerce orders for each company (Sonae and Wells)
322 - Integrated network	Scenario where both companies share transports to supply stores and to fulfil e-Commerce orders.

The following table (Table 8) shows the transport configuration designed for this scenario. From the point of view of service to the nodes in the network, the level of service is maintained. Each node has two routes each day to distribute the ecommerce orders. The number of vans used in each network for urban distribution is 10 vans, in total 20 vans per day. In the integrated scenario, it is reduced to a total of 18 vans, used in a collaborative way, to serve the two networks.

Table 8: Transport configuration data

Scenario	Routes per node	Vans active per day	Vans trips per day
321 - Independent	2	20 (10 per network)	40
322 - Integrated network	2	18 (shared for 2 network)	30

The demand used in this model is based on data provided from the company. The model contains information about stores and darkstores in the Porto area. There is also the e-commerce client's location, which are distributed over Porto area. For simulation purpose we have defined a limited scenario as a fraction of real demand, in this case the average amount of orders per day and per store is 24, and per darkstores there are 40 orders per day. The average amount of orders is 224 orders per day, 1344 per week.

5.1.4 Simulation Results

In order to evaluate the influence of network integration, three types of indicators have been used: operational, economic and environmental. The main results are shown below for one week of simulated time.

From operational point of view (Table 9), integrated scenario (322) obtains a better fill rate than the Independent scenario, an increment of 15%, resulting from reduction in total trips (from 40 to 30 per day).In addition, Integrated scenarios deliver better results in delivery lead time due to more time options available to travel. While delivery vans are shared, the time window when orders can be delivered gets completed can be more evenly distributed.

Table 9: Operational results in scenario in LL3.

Scenario	Orders	Fill rate	Lead time[h]
321 - Independent	1.344	67%	8.36
322 - Integrated network	1.344	82%	6.84

From the economical perspective, two main dimensions have been considered, the preparation cost and the transport cost. In this scenario the cost of transport is also divided in two parts, the fix cost (associated to the van activation) and the variable cost (associated with the distance travelled by the van). The three categories defined are:

- C1 - Preparation cost: cost of preparing and order. Takes in count the picker cost and the preparation rate.
- C2 - Transport fixed cost: the price of activating a delivery van (75€/van/day)
- C3 - Transport variable cost: cost per km in delivery (0.5 €/km)

Regarding the following table (Table 10) from the economical perspective, the integrated scenario has better results. The reduction in the number of transports gets reflected in transport fixed costs (activation of the delivery van). Variable transport costs are reduced by the synergies that arise from sharing the distribution network with similar destinations.

Table 10: Economical results in scenario in LL3. (Weekly results)

Scenario	C2. Transport fixed cost[€]	C3. Transport variable cost[€]	(C2+C3) Transp Cost[€]
321 - Independent	9'000	2'187	11'187
322 - Integrated network	8'100	1'791	9'891

The total order fulfilment cost, considers the preparation cost and the total transport cost for the total amount of orders. The average fulfilment cost decreases approximate 1 eur per order, which represents a 10 % of the fulfilment cost.

Table 11: Economical results in scenario in LL3. (Weekly results)

Scenario	C1. Preparation cost[€]	(C2+C3) Transp Cost[€]	(C1+C2+C3) Total Order Fulfilment cost[€]	Total Fulfilment cost per Order [€/order]
321 - Independent	2'966	11'187	14'153	10.54
322 - Integrated network	2'966	9'891	12'857	9.56

From an environmental point of view, a reduction in CO_2 emissions is achieved through collaboration in urban distribution transport and the consequent reduction in kilometers travelled, as shown in the following table (Table 12: Environmental results in scenario in LL3.Table 12)

Table 12: Environmental results in scenario in LL3.

Scenario	Distance [km]	CO2[kg]
321 - Independent	4’374	2’187
322 - Integrated network	3’583	1’791

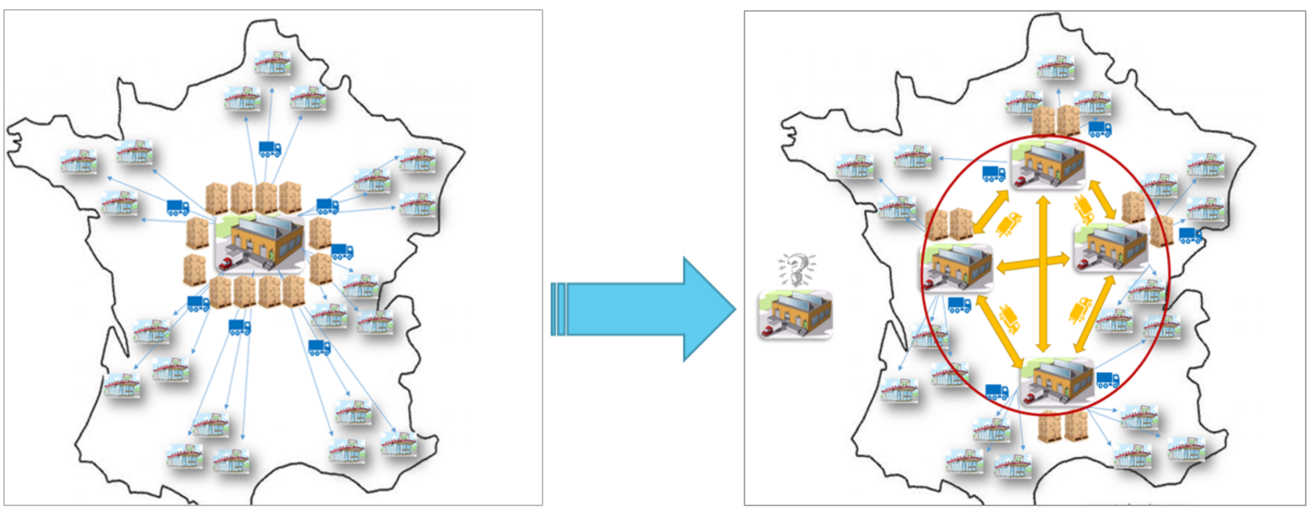
As a summary, the application of Physical Internet in this living lab through the collaboration between supply networks, produces positive effects from an operational point of view, increases the fill rate of the van, while improving the current level of service thought a reduction of the delivery lead time. From an economic point of view, it is favorable because it reduces transport costs while maintaining preparation costs, and the total fulfilment cost per order is cut about 10%. Furthermore, from an environmental point of view, it also achieves a significant reduction in CO_2 emissions.

5.2 Simulation LL4 Warehousing as a Service

The aim of this simulation model is to investigate the potential of e-Warehousing as a key enabler for the PI concept. Hence, this model will serve as the testbed for testing warehousing services structured under the PI concept.

5.2.1 Objective

The main objective of the simulation model in this living lab is to evaluate the impact of different storage locations. The goal of the system is to offer a better service quality at the best price, taking into account different logistics factors like the storage and the transport costs. This LL is focused in the storage and distribution strategies in the supply network. The ultimate vision is to achieve a network of networks. Unlike the current centralized structure, the future target is to achieve a distributed network of products across the Physical Internet, as shown in the figure below.



Current network

Physical internet network

Figure 17: Schema of LL1 distribution strategy.

5.2.2 Simulation Model

In this business case the simulation network is country level. It includes a group of warehouses around the country of France and the transport network used to move the freight between them. The container level reference from this living lab is the pallet.

5.2.2.1 Simulation Elements

The principal elements of this LL, according to the Generic PI Case Study framework are:

- PI Nodes
    - Central Warehouse
    - Regional Warehouse

    - Stores (clients)
- PI Corridors
    - Truck (inter-city)
- PI Roles
    - Sender
        - Freight Forwarder
    - Receiver
        - Clients
    - Transport
        - Truck
    - Coordinator
        - SB

Previous versions of this document have described the sources of information to be used in simulation models. The main indicators, and the first model prototypes that have been developed to validate the new distribution concepts. This information is available in annex of this document.

5.2.2.2 *LL4 Sim V.2.1*

The third version of this model includes a GIS representation of the movements, in addition to the layer view of the GPICs. The layer view has been modified from right-left distribution to top-bottom, so it's easier to identify layers and transporters moving between and through the layers. The simulation model has now a better interface to work with, turning the model more interactive and intuitive to search information at runtime.

The simulation model is composed by 1 central warehouse (located in Paris), layer 1 in the following Figure (Figure 18), 3 regional warehouses, layer 2 and 9 clients' locations in the layer 3. The number of nodes has been reduced from previous simulation model to identify better the key points of the proposed strategies. Once the strategies are well defined and all the systems and services working, it is easily scalable to a bigger network.

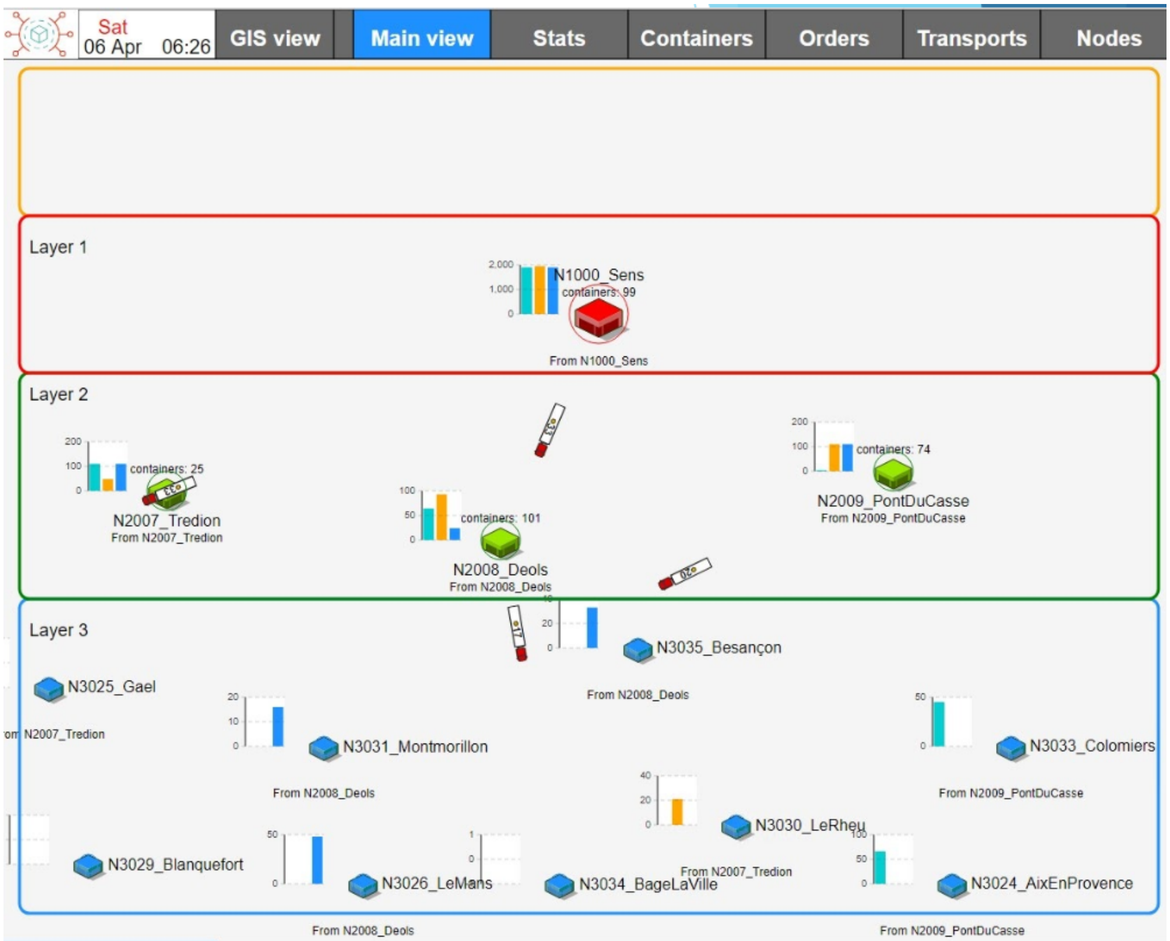


Figure 18: Schema of LL1 distribution strategy.

5.2.3 *Simulation Scenario*

In this Living Lab, we have defined one scenario in order to be able to compare the effect of replenishment source selection dynamically in a Physical Internet network. The main objective is the evaluation of the impact of dynamic replenishment strategies over a physical internet network. This living lab has two main dimensions to evaluate, the order fulfilment strategy and the replenishment strategy. The replenishment strategy has two options, which are static replenishment and dynamic replenishment. In static replenishment, each warehouse defines its replenishment needs for a time period attending to a forecast. In this period, replenishment is made with a constant frequency from central to regional warehouses, who finally serve clients. In dynamic replenishment, each warehouse defines its security stock strategy. According to these strategies, when minimum stock is reached, the warehouse requests new replenishment transport from the central warehouse .

The following table (Table 13) contain the main two dimensions for the analysis, the replenishment strategy and the delivery strategy, each one has two possible options:

Table 13: Main dimension description.

Dimension	Level	Description
Replenishment strategy	***(ST) Static***	Fixed periodic replenishment.
	(DY) Dynamic	Stock dependent replenishment
Delivery strategy	***(NE) Nearest***	Items served from nearest warehouse
	(ST) with Stock	Items served from warehouse with enough stock

One important factor to highlight in this Living Lab is the ability to select dynamically the best warehouse to serve the products over a Physical Internet Network. In other words, it is possible to dynamically change the configuration of the replenishment network of the final warehouses according to different factors. Another key point is the capability to evaluate the influence of PI-like strategies in replenishment. To evaluate the influence of this decision and strategies, we have created three scenarios. All the scenarios are based in a regional distribution model, which enables more variety of strategies. According to the GPICs definition, there are three levels of nodes. In the first scenario, traditional strategy is evaluated. In the second and third scenarios two PI-like strategies are evaluated. The main details from each scenario are described in the following table (Table 14):

Table 14: Brief description from each scenario in LL4.

	LL4 Scenario Description
411 Static – Nearest	This scenario has a static, fixed, assignment of regional warehouses (level 2) to customers (level 3). The replenishment orders are uniformly distributed in this scenario. Clients (Level 3) are always served from the same warehouse (Level 2), even though, in some occasions the warehouse can run out of containers (serve always with available stock).
412 Dynamic – Nearest	Replenishment strategy is dynamic in this scenario. The replenishment of products is variable, depending of the variability of the stock of the client.
413 Dynamic – Stock	This scenario has the same rules than previous one (412) but with the additional condition that if a warehouse does not have enough stock to serve an order, that order is served from a nearby warehouse that does have enough stock. There are daily transports connecting Level 2 nodes (regional warehouses), in case a client must be served from a warehouse which is not its nearest one because it has no stock of containers.

In order to effectively compare the options, the demand from final customers is the same in all the scenarios. In addition, the amount of transport available at each node is the same under both scenarios. Note that although the transport availability is the same for all the scenarios, the use of the shipment may be different. If no transport is required on a particular day, it is not considered in the measures for the indicators.

5.2.4 *Simulation Results*

The simulation period evaluated represents 28 days (4 weeks), which provides a bigger scope and more stabilized period of time to evaluate scenarios and get results. The main flow in these scenarios is from regional warehouses to final clients' locations. There is a secondary flow from central warehouse to regional ones, which represents the replenishment flow. The clients request on daily basis, but the replenishment can be done in two ways. On the one hand, replenishment can be defined previously, with a forecast of the warehouses needs. On the other hand, warehouses only ask for replenishment under certain conditions, preventing from a warehouse saturation and moving too much containers.

(Figure 19) shows the example of the representation of the main indicators of the performance at the end of a simulation – in this case for LL4. The graph shows the evolution of the moving/waiting containers in the network. It also shows the mean fill rate of the regular transports and the value of selected economic, operational and environmental indicators.

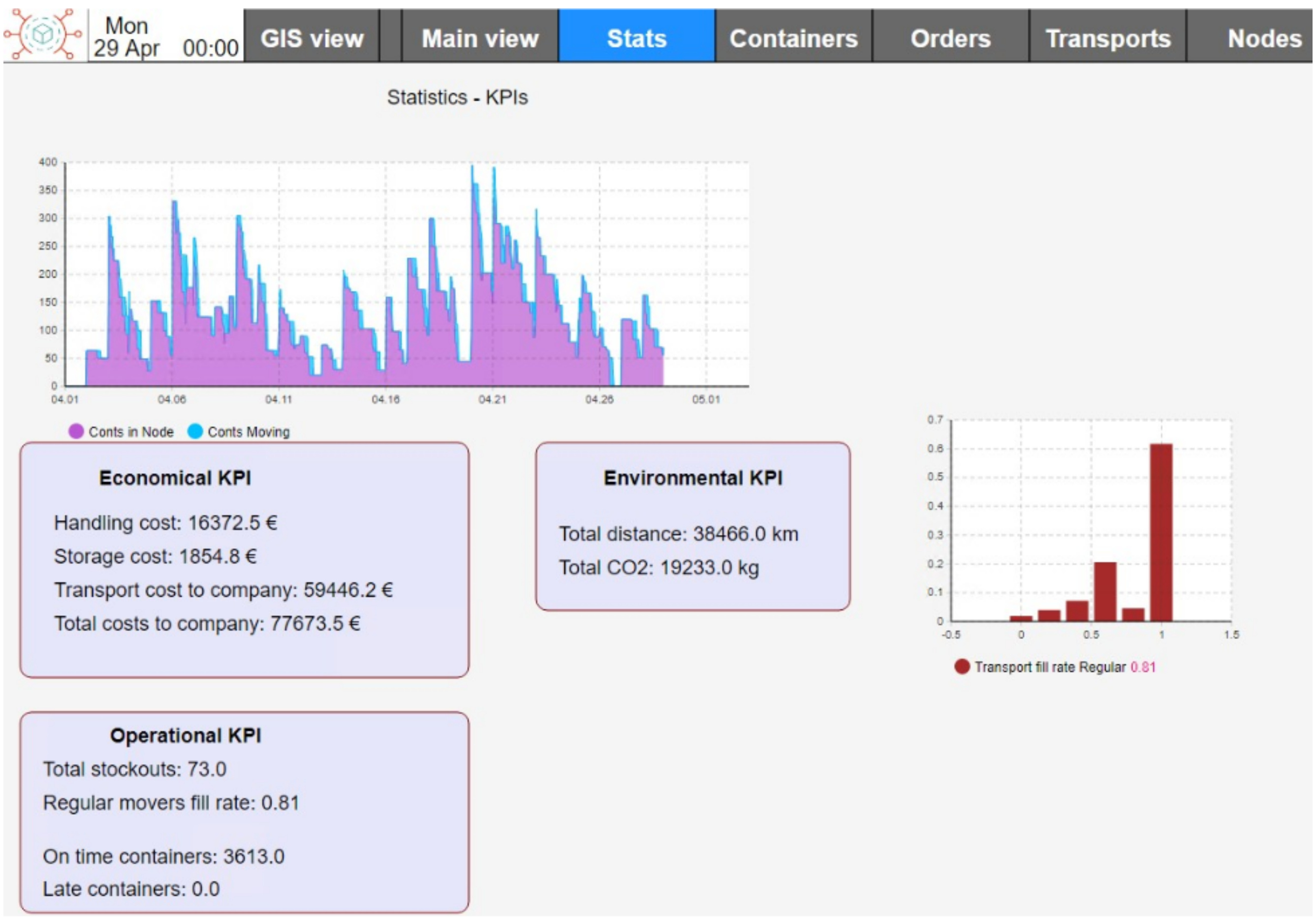


Figure 19: LL1 simulation statistics.

The following tables contains the indicators obtained from the simulation model with the different scenarios. Before the final comparison, each scenario has been replicated several times in order to evaluate the minimum frequency of transport required. The indicators are grouped in three categories: operational, economic and environmental.

Regarding the scenarios, **from the operational point of view** (Table 15) the best scenario in terms of distance is the "dynamic - serve with the available". In terms of stockout, "dynamic - serve from nearest with stock" is the best scenario, because the strategy prevents from stockouts. When looking at the mean fill rate, the three scenarios share results. In general terms, it would depend on the relative importance of the distance and the stockouts to take the decision about the best strategy.

Table 15: Operational KPI in LL4.

idScenario	desScenario	Total distance	Stockouts	Mean fill rate	Urgent
411	**Static - Nearest**	55'049.00	85.00	56%	4.33 %
412	**Dynamic - Nearest**	38'466.00	73.00	66%	11.25 %
413	**Dynamic - Stock**	40'640.00	-	65%	14.20 %

From the economical point of view, "dynamic - serve with the available" gets the best results in absolute terms, but the "dynamic - serve from nearest with stock" scenario gets slightly better results in the aggregated case.

Table 16: Economical KPI in LL4.

idScenario	desScenario	Handling cost	Storage cost	Transport cost	Total Costs
411	**Static - Nearest**	22'603.5 €	2'397.0 €	84'763.9 €	109'764.4 €
412	**Dynamic - Nearest**	16'372.0 €	1'854.8 €	59'446.2 €	77'673.0 €
413	**Dynamic - Stock**	16'982.0 €	2'028.0 €	61'184.3 €	80'194.8 €

Regarding the CO2 emissions, the second scenario is the one that achieves the greatest reduction in CO2 emissions, due to the reduction in the use of transport and the reduction of distance travelled. In this case the CO2 emissions are directly related to the use of transport and they are proportional to the number of kilometers traveled by the transports.

Table 17: Environmental KPI in LL4.

idScenario	desScenario	Total CO2 [kg]
411	**Static - Nearest**	27'524.50
412	**Dynamic - Nearest**	19'233.00
413	**Dynamic - Stock**	20'320.00

This scenario analysis has assessed the impact of a dynamic replenishment system deployed on a Physical Internet distribution network. Different improvements in the models evaluated have been identified. From an operational point of view, the analysis shows a model that reduces stockouts and improves the transport fill rate. From an environmental point of view, the model reduces CO2 emissions. From an economic point of view, it is possible to reduce the cost of transport, taking advantage of the use of regular transport.

6 PI Business Cases physical simulation

The concept of physical simulation in the PI framework refers to the simulation of models that can be performed with real data/events fed from the physical world. The physical simulation will materialize with sources of information that come from data sources, available in the living laboratories of ICONET.

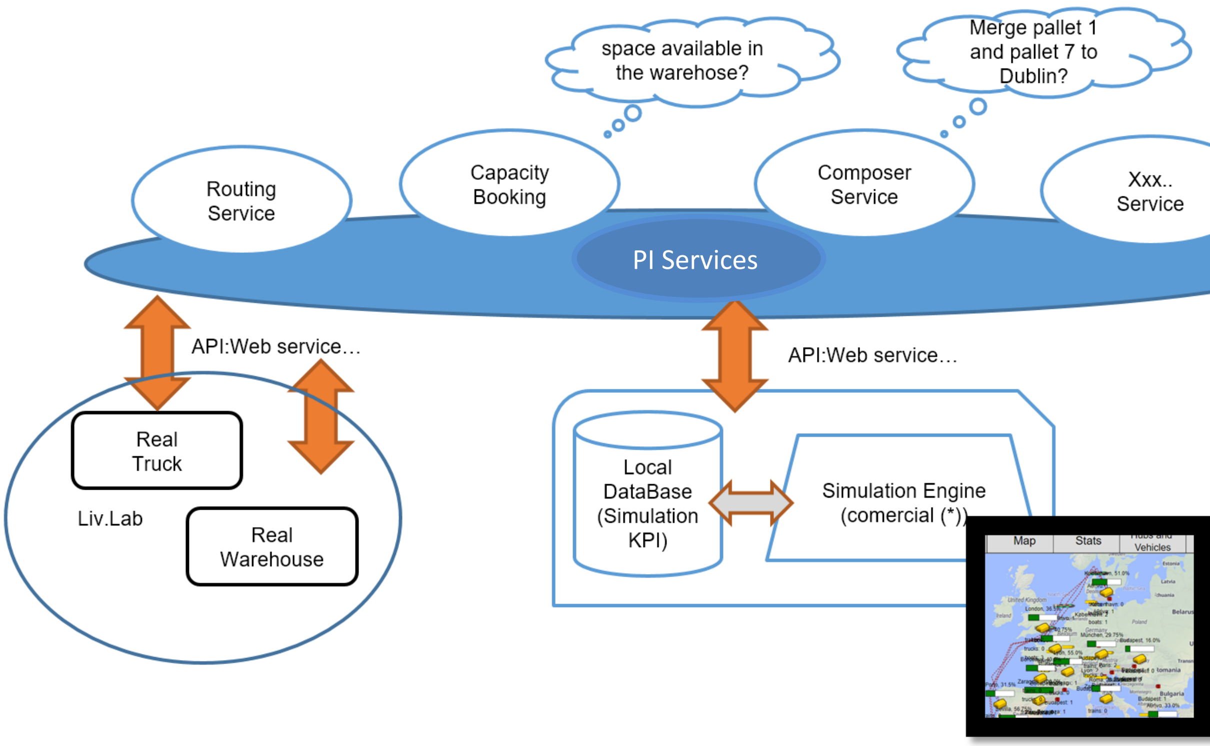


Figure 20: Initial schema of the connection from the simulation engine with the IT Platform in the physical simulation.

The information of the physical world will be connected to the simulation models through data exchange interfaces. (i.e. from a common information management platform). In the information platform, the different physical elements, such as a truck or a container, can give information about their arrival at the destination, their departure from the port or their GPS position at a certain time. The digital simulation can receive this information and, consequently, apply the management rules of physical internet management to evaluate the possible evolution of the network taking into account the real data that has just received.

In addition, the simulations can use different PI services like algorithm services or information services through integration with APIs. The simulation model calls the APIs to request different types of information, such as nodes, routes or groups of containers. The main services involved are the following:

- **Networking service:** Definition of the assets available in the network, connections between the nodes, capacities and other attributes.
- **Routing service**: Identify the best route decisions, where best route might be on the basis of costs, throughput or emissions, and also includes optimization that considers hub topology, network state, and cargo type.
- **Shipping services**: Management of the procedures and protocols for configuring the quality of service, monitoring, verifying (acknowledgment), adjourning, terminating and diversion of shipments in an end-to-end manner.

- **Encapsulation services:** identification and propose efficient encapsulation assignments of products within specific PI containers, considering existing and emerging standards for physical interoperability.

6.1 Cloud Simulation environment

In order to reach a larger audience for the project, a cloud simulation infrastructure has been developed in the project. The cloud simulation environment, provides a space to run the simulation models developed in the desktop application using just a web browser. The models can be uploaded in the cloud environment with public or private access. Thanks to this feature, starting from a single simulation model, different users can use the simulation models and launch their experiments and make their scenarios. In addition, thanks to the cloud simulation environment, the results from the simulations are calculated fast, which allow the user to run multiple simulations with small changes and check for the best option to its problem in a short time.

The Simulation Cloud Environment (CSE) has been integrated in the PoC platform of the ICONET project in order to share information from the simulation elements and the ICONET services. The model creation is realized as shown in the following figure (Figure 21). The simulation model first starts with the development on the local machine. According to the process design specifications and available information sources. Once the model is validated, the model is uploaded to the cloud platform so that it can be shared with other users. From the cloud environment, the simulation model could be connected to the ICONET services, to exchange information with them. The final simulation user could interact with the simulation models or with the ICONET services directly.

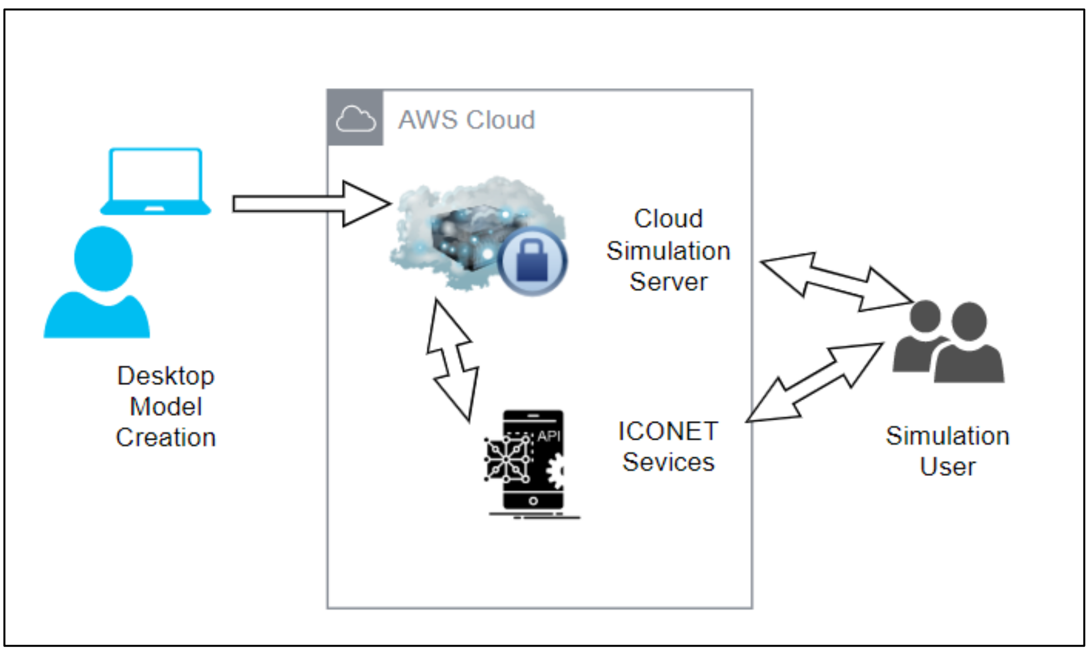


Figure 21: Cloud simulation schema

The following image (Figure 22) illustrates the main modules of the simulation tool in the desktop environment. On the left side, a tree diagram is shown in which the various components (PI Node, PI Container, PI Transport...)

can be accessed. In the central section there is a 2D representation of the main elements of the simulation. On the right side are the properties of the different elements selected.

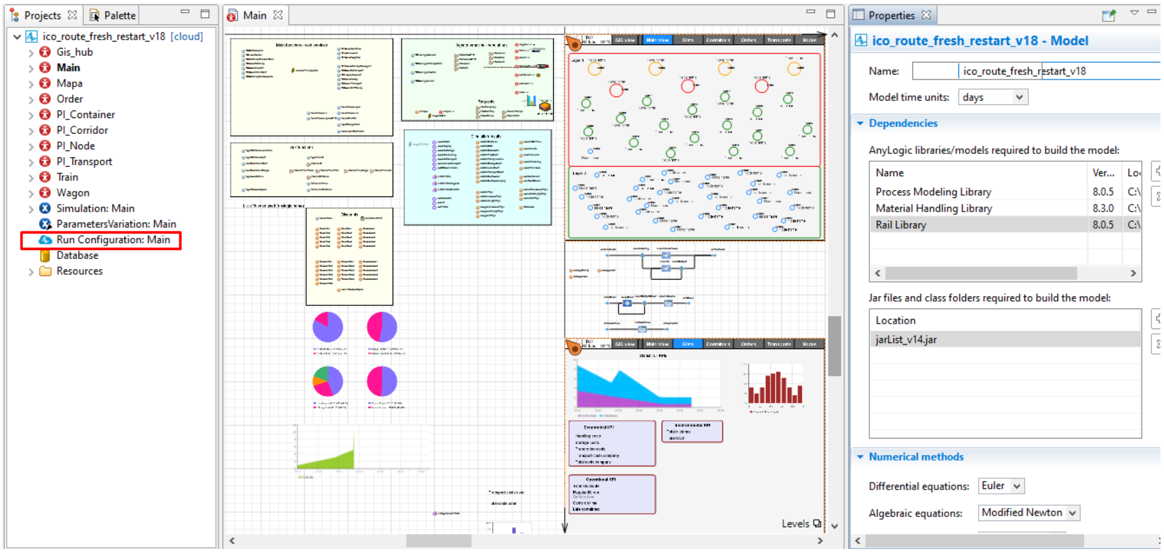


Figure 22: Diagram of the main parts of the modeling tool

An important part of the Modeling System is the identification of input parameters and output results. In the following image (Figure 23) there is a screenshot of the main input data, in this case the interface files and the living lab parameter selection. From the results perspective, different indicators are shown such as the costs, the fill rate histogram, the travelled distance or the CO2 emissions.

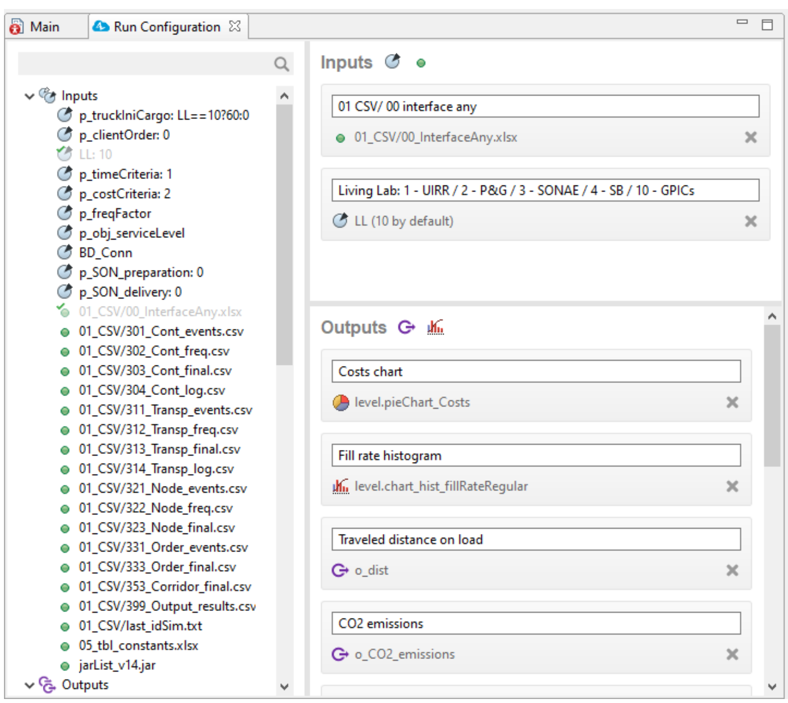


Figure 23: Example of Input parameters and Outputs for the simulation model

After uploading the model to the Cloud Simulation Environment (CSE) the models are accessible through a URL accessible from any browser. Access to the models will be controlled through the definition of users and passwords established by the project members. In the following image (Figure 24) there is an example of the log in screen for the CSE.

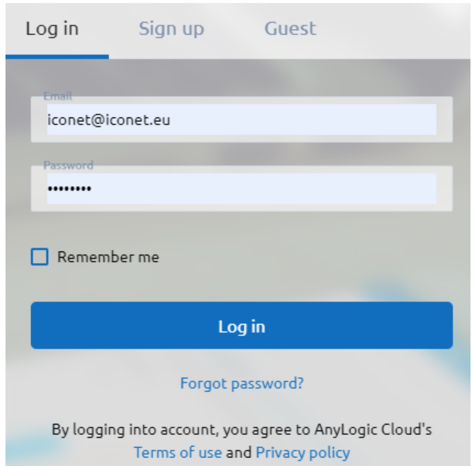


Figure 24: Example of Login Screen

After the log in process, the user is conducted to the main screen, where there is a list of different of models are listed. The CSE contains a group of simulation models. The user could select and order the simulation with different criteria like Rating, number of runs, Date or simulation model name.

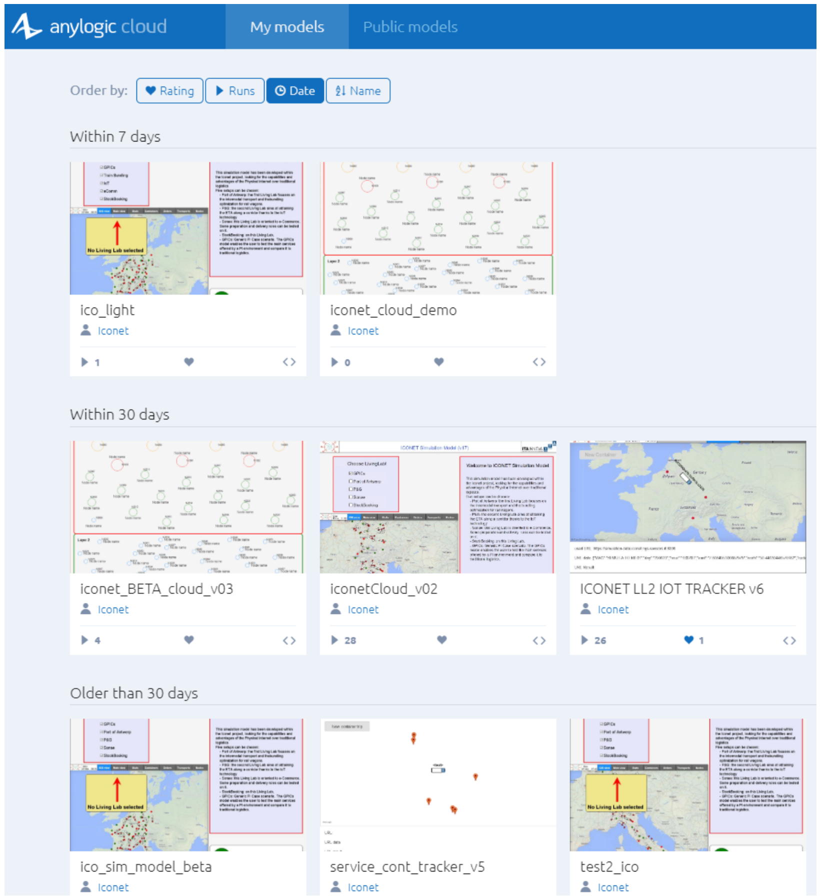


Figure 25: Group of simulation models

When the user selects a model, a screen like the one below appears, in which the user can run the model directly on the cloud environment. The temporal evolution of the model can be displayed from any web browser.

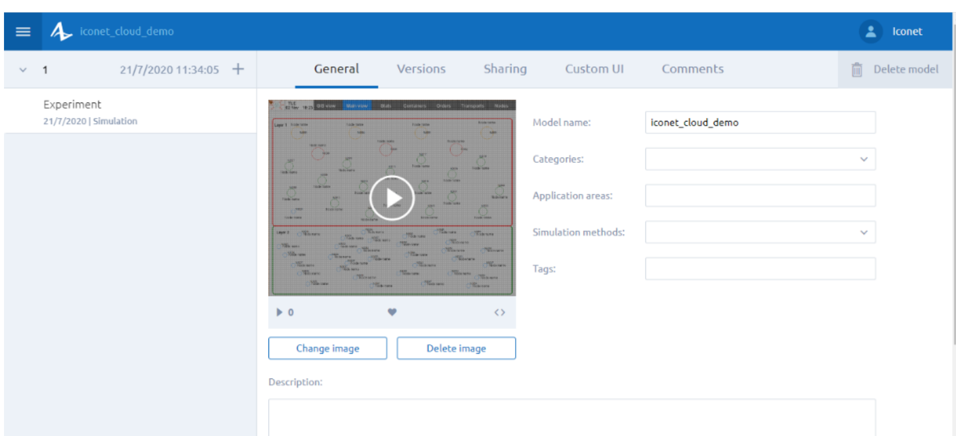


Figure 26: Cloud Simulation Model

The following figure illustrates an overview of the physical Internet supply chain representation. In the upper part of the image there are different buttons to access the visualization or analysis screens, for each of the components such as by container by order, or by type of transport. The three levels of the PI network are represented in the central part. In the upper section is level one in this case with one node, in the middle section is level 2 with 3 nodes, the lower part is level 3 with 9 nodes in this example. On the right side there are the simulation controls and the console for the different messages that appear during the simulation execution.

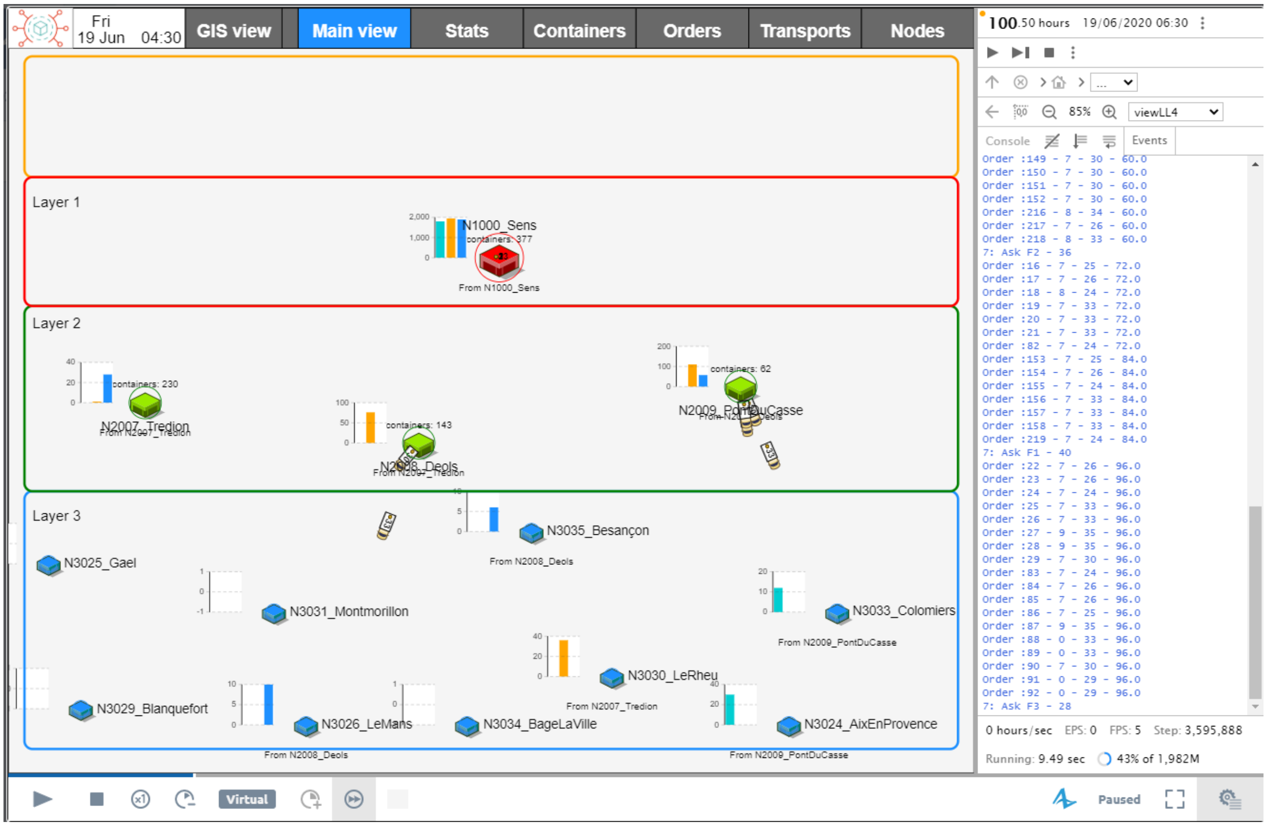
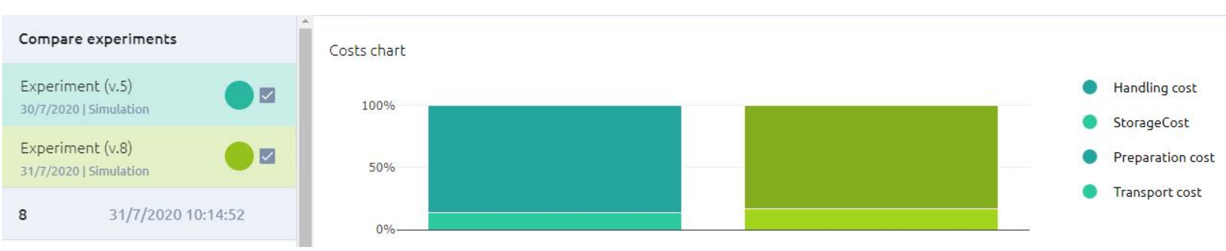


Figure 27: Cloud simulation execution

The cloud simulation environment also enables different experiments to be run simultaneously. The following image (Fig XX) shows the comparative results of three experiments performed on the same model. The tool provides a color code to be able to compare the value of the different indicators in the different scenarios analyzed.



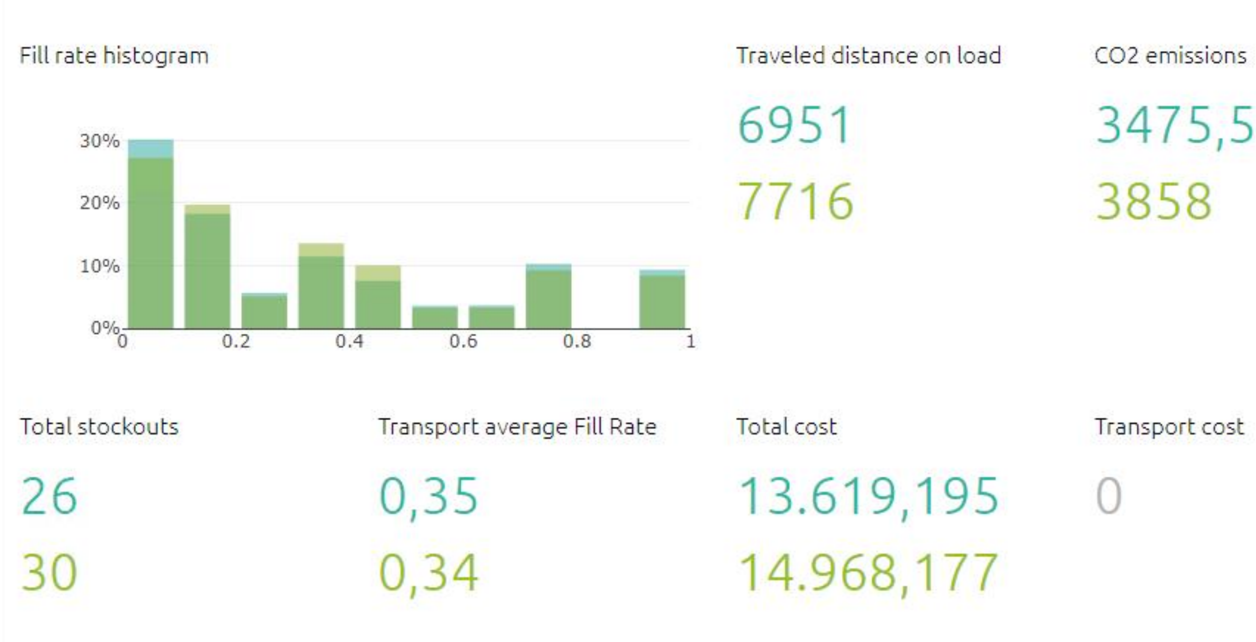


Figure 28: Cloud experiment result example

6.2 Cloud Service Integration

The cloud simulation system permits interaction between the virtual elements of the model with the different ICONET cloud services. The services perform the calculations and operations to coordinate the different agents in the PI supply chain taking in count the dynamic interactions: resources optimization, data collection, connection to physic world, decision making, etc. The first step to do a proper integration of API Services into simulation models is to validate the common language to send and receive information between them. In the ICONET project, the first API service integration has been tested with IoT tracking service.

The following image shows an overview of the message interchange between the simulation system and the IoT cloud services. In this scenario, the objective of the model is to represent the movement of trucks through the PI nodes and emulate the messages of the physical tracker that travels with the containers. This simulation is used to validate the correct performance of the services, authentication systems, refresh rates, status, etc.

The message flow starts from the simulation, with the declaration of a new shipment to the Shipment service API. The service returns the new shipment ID. In the next step, the simulator sent information about the initiation of the journey (status started), receiving a confirmation from the Shipment Service API. At this point the container initiates the journey through the PI network in the model. The simulation tracker sent data every 10 minutes to the Tackers endpoint. At the end of the journey, when the container arrives to final destination, the simulation informs new status (status over) to the Shipment Service API. The following image (Figure 29) represents this exchange of information.

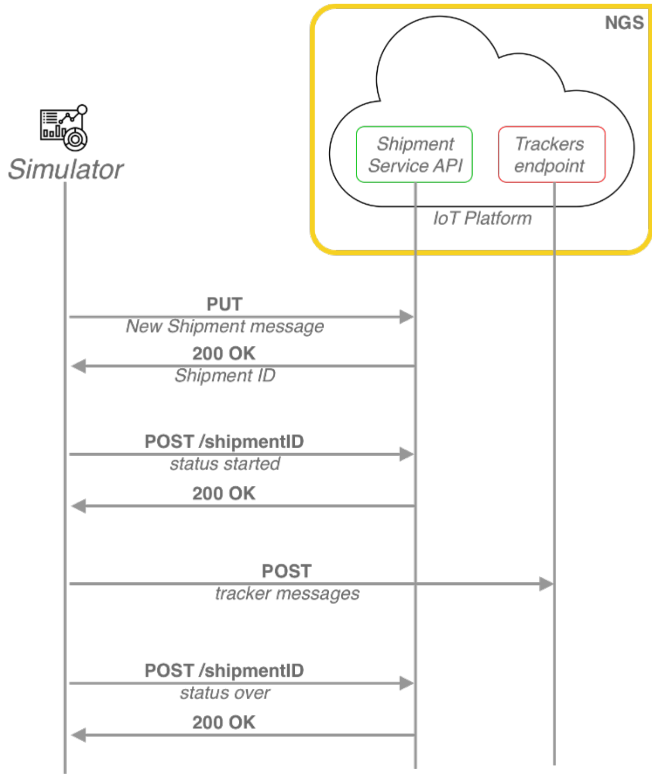


Figure 29: Simulation – Service messages exchange diagram

The messages exchanged contain different information fields. The following image (Figure 30) shows the fields of a message exchanged between the simulation and the IoT Cloud service. Fields such as identifier, day, time, latitude, longitude, temperature, humidity or different acceleration values recorded by the accelerometer are shown.

```
# Tracker Message
{
  "MAC": "SI:MU:LA:TO:R0:01",    # identifier of the trackers
  "day": "080520",               # day in the format ddmmyy (May 8th 2020 in the example)
  "hour": "102419",              # hour in the format hhmmss
  "east": "10.48891",            # longitude in decimal degrees
  "north": "43.68538",           # latitude in decimal degrees
  "code": "0x00",                # status code (see slides on code)
  "temperature": "27.5",         # temperature expressed in Celsius degree
  "humidity": "30.85",           # humidity expressed in percentage
  "light": "3.74",               # luminance expressed in lux
  "bat": "9.55",                 # battery value expressed in volts
  "ax": "16",                    # acceleration on x in milli G
  "ay": "-9",                    # acceleration on y in milli G
  "az": "985"                    # acceleration on z in milli G
}
```

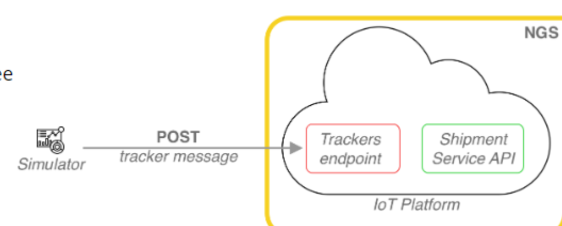


Figure 30:Service message fields.

The process simulation allows integration with ICONET services to validate the operation of the services and to evaluate their impact on the processes in the companies participating in the Living Labs.

The following diagram (Figure 31) shows an example of the interrogation of these services with the simulation. Firstly, the simulation is started and the parameters of the scenario to be simulated are configured. Then the networking service is invoked to obtain the list of nodes in the model and the number of transports available in the network. Finally, the shipping service is called to obtain the list of orders to be evaluated in the simulation.

Using this information the simulation is capable of initiating the dynamic representation of the movement of the containers through the physical network. The containers begin the journey through the physical network. At each node the containers request the encapsulation service to obtain the best grouping or splitting of containers. The transports also ask the routing algorithm for the best route at this time according to the information available on the network and the state of the containers. The simulation progresses over time and when the orders are completed, the results are recorded in order to obtain the impact indicators.

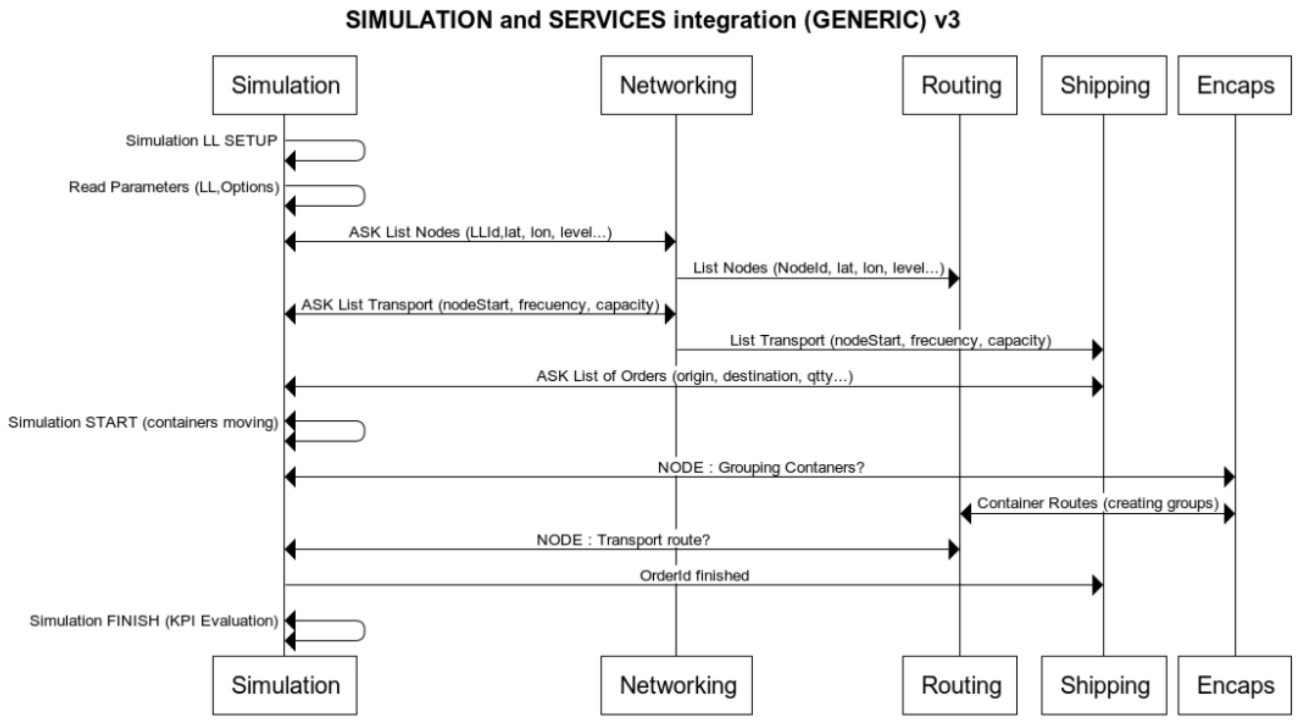


Figure 31: Simulation model and services interaction schema

6.3 Simulation LL1 - PI Hub-centric Network

In the Port of Antwerp (PoA) there are different transport modes. The current modal distribution is: barges 37%, road transport 47%, pipeline 5% and rail transport 11%. One of the objectives of the Port is to increase the use of train transport through the use of the Physical Internet rules.

The objective of this simulation model is to validate and evaluate the impact of the application of PI rules in the operation of port terminals. In this Living Lab the scope of the simulation model is in the integration with external services to interact with real data in real time and to interact with services like real time optimization engine to improve the use of intermodal transport.

The goal of the PI-centric approach in this LL is to streamline the mega-hubs' operations, reducing congestion and bottlenecks in the flow of goods, especially in left/right bank trips. The LL provides the opportunity to simulate and study PI concepts and network operations at two different scales: intra-facility inter-center network and intra-country inter-state network.

Simulation services for best route calculations in particular in case of disruptions, e.g. late deliveries of loading units, departure train path not met, works (phase 2, PI Optimisation and real-time planning adaption)

6.3.1 Objective

The Ports' Rail Traffic Systems and platforms integrated with ICONET routing and optimization services will be the basis for creating the first PI network in Antwerp for all involved stakeholders and prototyping the PI Hub as a Service. The general objectives of this Living Lab are:

1. Primarily a better coordination of the port-centric network with connectivity infrastructures, accelerated towards the Physical Internet with the efficient use of information tools providing near real-time transparency/visibility to the logistics and transportation operations for all relevant stakeholders, and in particular those providing hinterland connections (rail, road, barge operators and forwarders), terminals and shipping lines, customs and other authorities.
2. Increment of modal shift to railway transportation through better capacity/slot management
3. Improvement of tracking and tracing management, transshipment operations, collective load planning, transport management and information management with all railway stakeholders.

The specific objectives are to evaluate different parameters from the network performance like:

- Improve efficiency in the use of port facilities.
- Validation of analytical algorithms designed to optimize route decisions, taking into account current "network" circumstances, along with the topology of the three ports, network state, point to point (node to node) PI network speed and latency, and type of cargo.
- Enhancing ICONET's routing and shipping services by consolidating existing intermodal services with available railway capacities within the PI network, and applying PI optimisation models.
- Increment the modal shift to railway transportation through better capacity/slot management.
- Improve container flow efficiency. Improve transport robustness against delays or congestion.

6.3.2 Simulation model

The simulation model of this Living Lab represents the interconnection of two PI networks, the port internal network and the external network related to the activity of the Antwerp port. The internal network of the port is composed of the different maritime terminals. They are connected to each other by water, road or rail. The external network of the port contains other elements of the PI network that which are inside the continent until the final receiver.

The maritime and continental hubs and terminals of the ports will be considered as the PI Nodes, whereas trains, trucks and barges will be the PI transports, and the respective train, road and barge lines/services will be the PI Links.

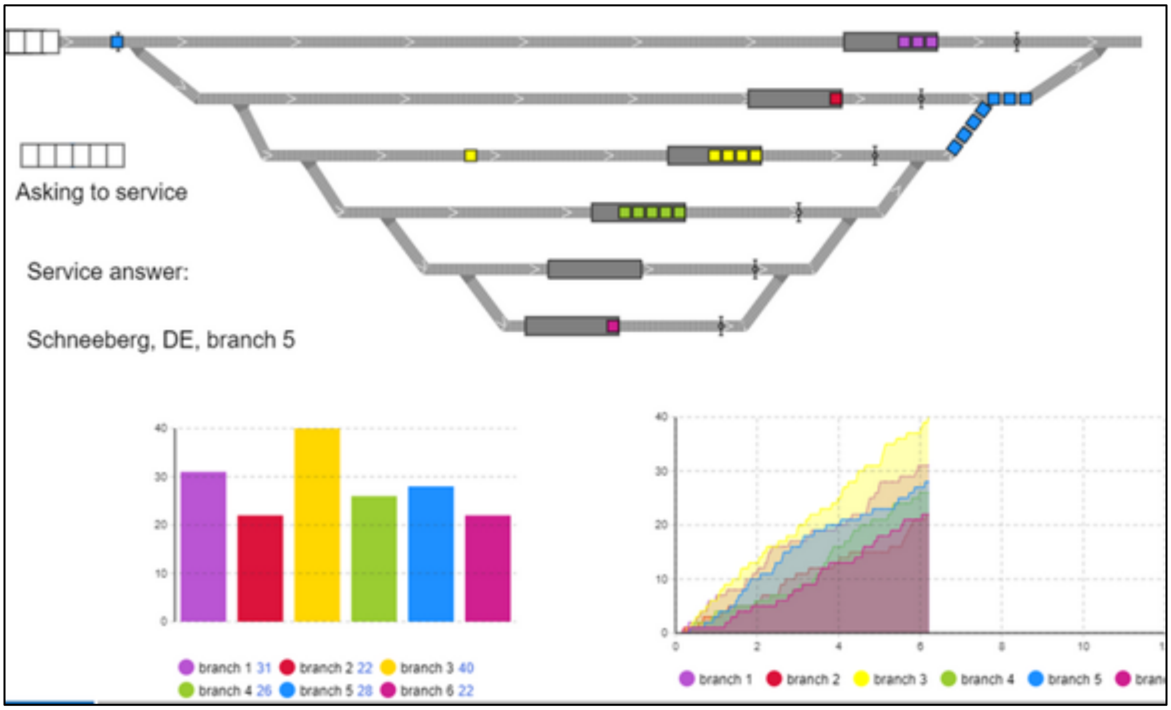


Figure 32: Schematic example view of the PI Network

6.3.2.1 *Simulation Elements*

The principal elements of this LL, according to the Generic PI Case Study framework are:

- PI Nodes
    - Source: Distant port in the sea. Containers enter the network from deep sea.
    - Terminals: There's a terminal for each way of transport (barge, train, truck).
    - Intermodal nodes: Nodes where load can change it's way of transport.
- PI Movers
    - Road (truck)
    - Railway (train)
- PI Roles
    - Sender
        - Deep sea terminal
    - Receiver
        - Freight fowarders
    - Transport
        - Train
        - Truck
    - Coordinator
        - PoA
        - Rail authorities.
- Cloud Conections
    - Routing algorithm
    - Container Sequence Optimization

6.3.2.2 *Cloud service: Optimization for crane operation*

In the following image (Figure 33) there is an initial description of the main connection of the PI cloud services. Starting from the left side, the sender starts the PI journey sending some containers to the receiver, at the end of the PI network. The containers are loaded in a boat. The boat arrives at the port, at the Deep-Sea Terminal. At this point, the first PI service is called, the Sequence Optimization Service. The objective of this service is to calculate the best sequence to move the container by the cranes and the physical distribution over the container yard. The final sequence depends on the destination of the container and the relationship with the sequence of other containers. Finally, the node selects the best transport according to the different properties of each container, considering elements like the cost, the lead time or the CO_2 emissions. The transport selected could be a truck, or a train or a barge.

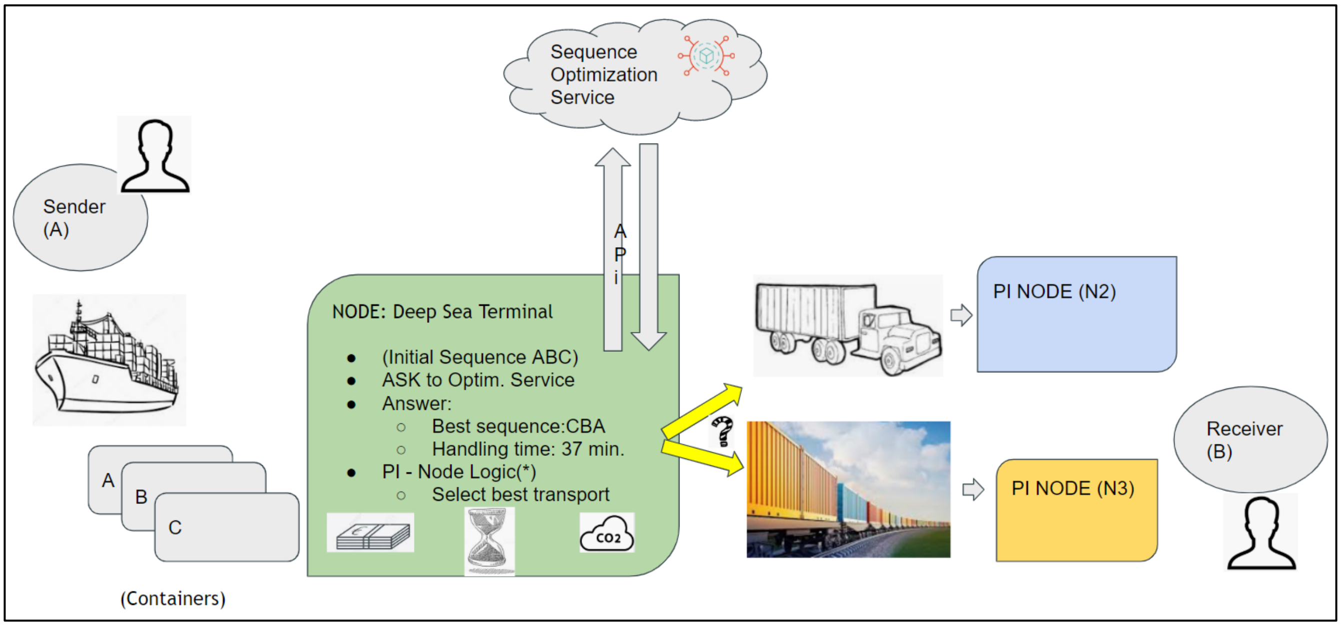


Figure 33: Schematic view of the cloud service connections.

6.3.2.3 *Cloud service: Routing*

In this Living Lab, containers arrive from distant port, through the Deep-Sea Terminal in the Port of Antwerp, to the final destination. In order to reach its destination, containers follow different routes by PI movers, which can refer to trains and trucks. The route is dynamically calculated by the PI routing Service, which provides the preferred route. When the container arrives its next node, evaluates the congestion in the path to get the following node on its preferred route. If the PI corridor is congested, container will ask again to the PI Routing Service for the best route from next possible nodes (preferably Level 1 nodes). Routing PI service prioritize on higher-level nodes, which provides more PI-movers and options to travel.

6.3.2.4 *Main KPIs*

The main KPIs in this Living Lab are focused in evaluating the performance of an intermodal network from an operative and economical perspective.

The anticipated improvement specific to living lab 1 are measured thought the followings KPI:

- Improved asset/infrastructure utilization : 10% reduction in wagon/truck empty runs, 5% additional capacity on railway, 5% additional loading unit runes
- Improved train path management : 30% reduced reaction time for ad hoc slot request
- Improved railway operations, 10% increased of train punctuality rates
- Improved terminal operations: 5% increase in direct train loading, 5% additional terminal capacity
- Improved sustainability parameters: 10% less congestion, 10% less CO2 emissions
- Cost reductions: 10 % operation costs of participant nodes

The definition of the concepts to be included in each of the indicators with the simulation model is as follows:

- **Increase use of train in cargo movement**. Percentage of load moved by each transport.
- **Service level**: ensure a high service level within the PI network.
- **Reduce cost-to-serve**: "Total cost" takes the aggregate costs in the model. Included costs are: delivery cost, handling cost and storage cost.
- **Preparation time**: compare preparation time using the crane sequencing service and not using it.
- **Delivery cost**: cost of the transport for the current order/PI container. Cost per order, accumulated with containers' steps (a container can be moved for several transporters when accomplishing an order). Transport cost * trip distance
- **Handling cost**: cost of preparing the order. Cost per order, accumulated with all the containers that are served because of it (i.e.: a weekly order will have containers serving each week).
  Handling cost = picker cost * preparing time.
- **Storage cost**: cost of having the goods stored. Cost per container (a container can be stored in several hubs when accomplishing an order).
  Order Storage Cost = storage tariff* Number of containers*days stored
- **Estimated C02 Emission**: The estimated C02 emission rate for the transport.

6.3.2.5 LL1 Sim V.1.1

The objective of the first version of this model is to validate the main flows of container in the port terminal and the relationships with the hinterland. In this model, inner port network is represented by the Deep sea node and three transport terminals. Furthermore, in outer port network, main intermodal nodes in center Europe are represented. Model has two main views: tree diagram (Figure 34) and GIS (Figure 35).

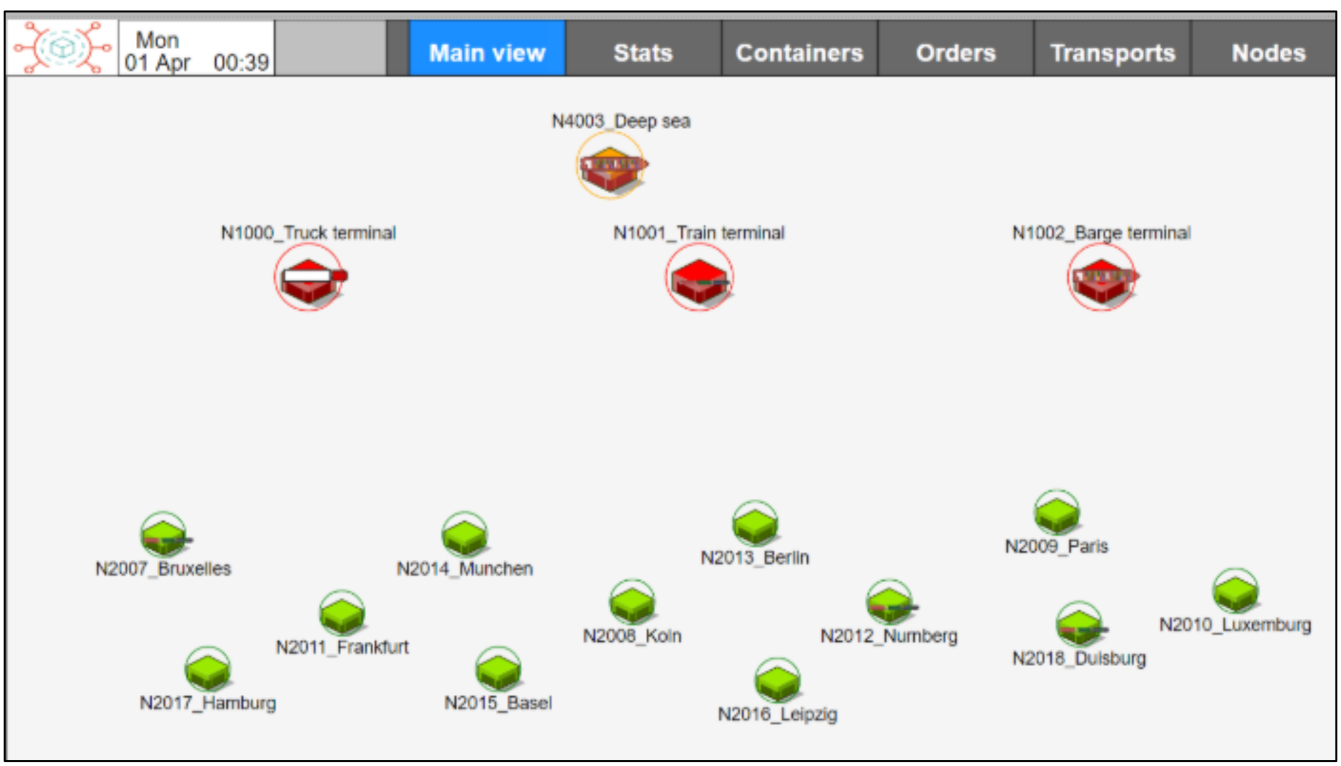


Figure 34: Initial simulation. Conceptual model.

The figure above (Figure 34) shows a schematic representation, in the form of a tree, of the distribution network of goods from the port. It starts from the sea terminal at the top, to the end customers at the bottom of the image.

The simulation model developed also provides a geographical representation of the supply chain. The following image shows the representation of the same distribution network in a geographical format, that is, the nodes of the chain are represented over a map, with the proportional distances between nodes. Depending on the type of analysis, or the result to be represented, one type of representation or another can be used indistinctly.

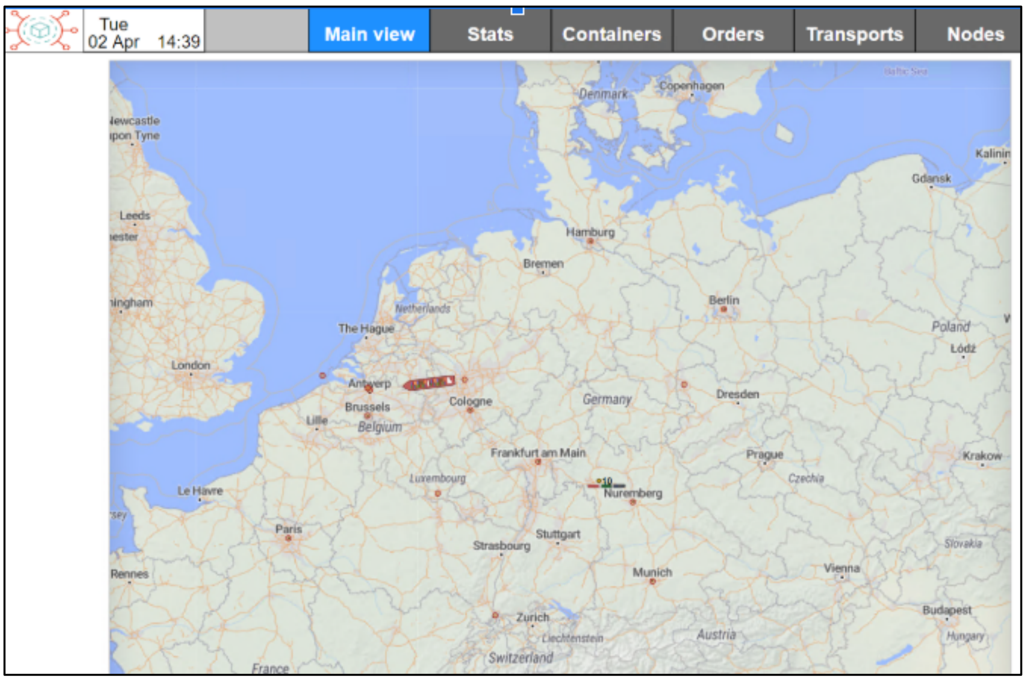


Figure 35: Initial simulation. Conceptual model.

6.3.2.6 LL1 Sim V.1.2

The second model developed has a more detailed distribution of the DST (deep sea terminal) and its railway connection with the rest of the elements of the network (bridges, bundling zones...). This model also focuses on the connection with PI services. Specifically, with services like Bundling Optimization Service or Encapsulation Service.

This simulation model has specific elements for container distribution in shipping terminals. The following figure (Figure 36Figure 37) contains one description of the main elements. The flow starts in two Deep Sea Terminals, red area, where the deep sea containers arrive. The Sea Terminals have a direct connection to each other. Both are connected to the bundling area, green area, where the different wagons are qualified according to their final destination blue area. In one general movement, the container arrives in a cargo ship, is discharged into a DST. A train can load wagons from one terminal and then complete its loading at the second terminal, until it reaches its maximum capacity. The train then proceeds to the bundling station. The train composition is separated at this point. The wagons are sorted by destination. From the bundling station, the train already formed, travels to final destination.

Figure 36: Initial with bundling operations.

6.3.2.7 LL1 Sim V.2.1

The LL1 V2.1 simulation model focuses in more detail on the sorting operation of the wagons within the bundling station. This model serves to validate the operation of the Optimization Service used to manage the bundling operation with different freight train configurations. The left side of the model represents the arrival of complete trains at the bundling station, ordered in the sequence in which they are loaded. At that point, a request is made to the Optimization Service. This service identifies which is the best branch to direct to the wagon, applying the PI optimization services. When the train is complete, or its departure time is reached, the train leaves the station by the right side, as it is shown by the blue train in the following figure (Figure 37).

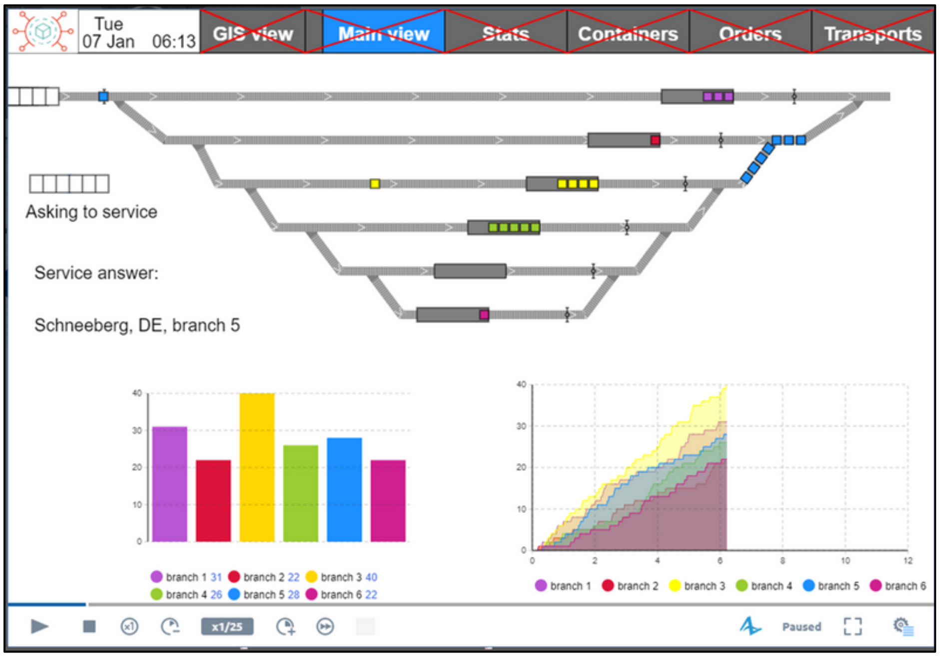


Figure 37: Train bundling operations model

This model focuses on the connection of the simulation model with the bundling operation optimization service. The following diagram (Figure 38) illustrates the sequence of events that are performed in the LL1 simulation model for integration with external services. The task flow is initiated in the simulation model by the arrival event of a loaded train at a marine terminal. The train leaves the Deep-Sea Terminals loaded with containers for multiple destinations. After a few kilometres, the train arrives at the bundling facilities. At that point, communication with external service begins. The simulation sends a message with the parameters of the train (train id, number of wagons, wagons id) to the cloud services. These are the parameters for the optimizations service. After the optimization calculations, the cloud services send a message to the simulation model with the answer, containing the train ID and the assignation of the branch to each wagon.

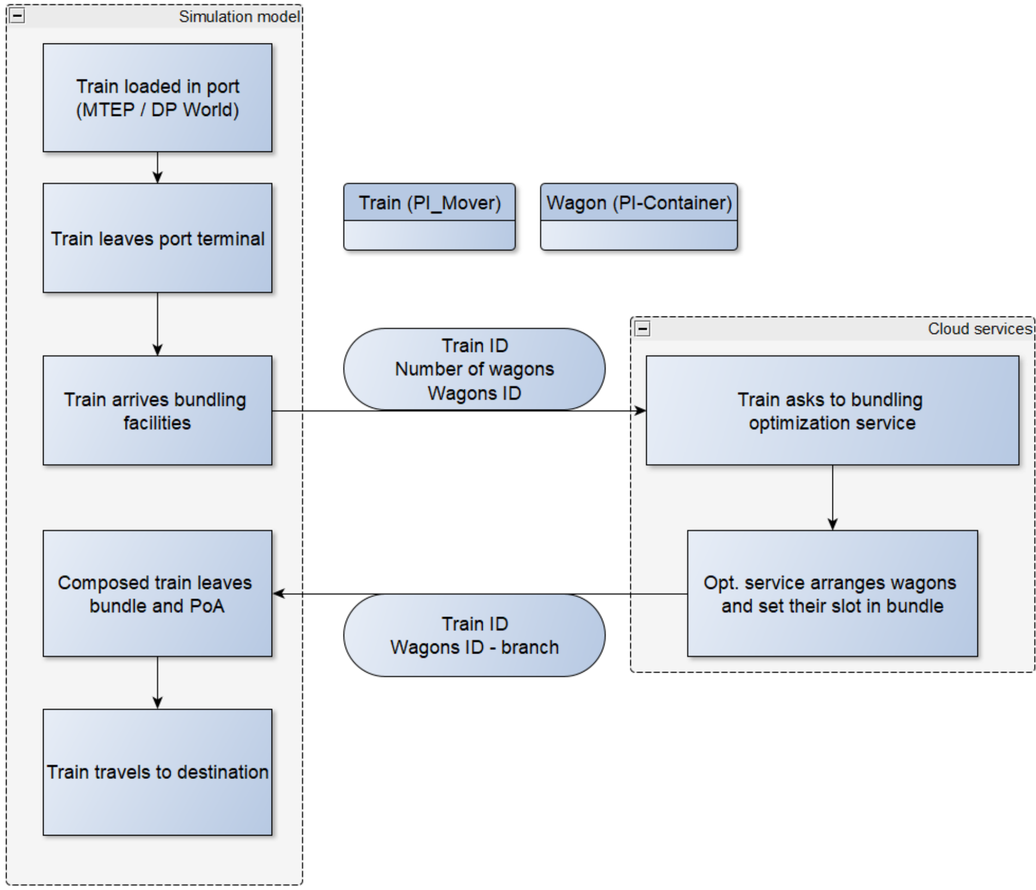


Figure 38: Simulation integration with Optimization services

The results of the final application of the services and the simulation integrated with the real data will be shown in the WP3 deliverables with the tests performed.

6.4 Simulation LL2 - Corridor-centric PI Network

The simulation of the LL2 is focused on the evaluation of the performance of the IoT and the Cloud-based ICT Infrastructure for PoC Integration to foster the intermodal transportation. The objective of the Living Lab is the selection of the best route for containers in the Antwerp - Milano corridor, using intermodal transportation and taking into account the current position of the container and network status. The following image (Figure 39) shows the main difference between the road transportation, were only three operations are taken: loading, road and unloading. On the intermodal transportation, several steps are taken, in addition to the loading, road and unloading, there are terminal movements for the container and the rail transportation.

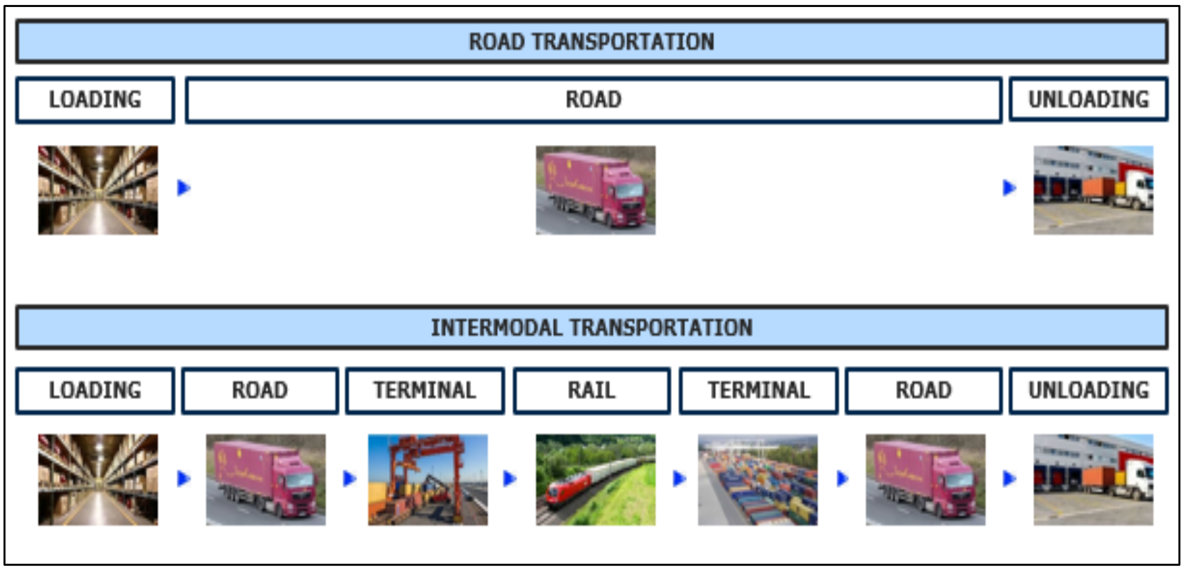


Figure 39: Comparative between road and intermodal transportation.

One of the main problems for the company is that at this moment it is not possible to track intermodal transportation from its origin to its destination. While supply chain visibility solutions exist for road transportation, where only one transportation mode is used, there are no supply chain visibility solutions for intermodal transportation, where more than one transportation mode is used. The lack of supply chain visibility on intermodal transportation is a barrier for its efficient use and is as a consequence a roadblock for both driving a modal shift and synchromodal solutions.

6.4.1 Objective

The general objective of Living Lab 2 is to examine the applicability of IoT through progressively transforming typical transport corridors into PI corridors, with the emphasis to enhancing the reliability of intermodal connections, paving the way to implement synchromodality at an operational level, and ultimately understanding decision making characteristics with regards to delaying or pulling forward loads or modal shift.

This Living Lab will provide the opportunity to simulate and study Physical Internet concepts and network operations at the scale of an intra-continental inter-country network.

The specific objectives of the simulation model for this Living Lab is to validate the following aspects:

- Validation the dynamic routing selection to avoid congestion.
- Integration of the IoT status services with Container status in the simulation.
- Validation of the data model structure to exchange information through the Cloud PoC integration

- Improve corridor environmental performance
- Define how integrated Living Lab data can be exploited for ICONET synchromodal services.
    - Measure and validate the reliability improvement of intermodal corridors.
    - Optimized utilization of logistics resources through IoT-enabled collaborative synchromodality.
    - Modal shift from road to more sustainable transportation for distances above 300 km.
    - Simulate and study PI concepts and cross border network operations at continental scale.

6.4.2 Simulation model

The simulation model of this Living Lab represents the movement of container in a continental corridor. Specifically, within the North Sea (Mediterranean Corridor) shown in (Figure 40). The container used in this corridor contains IoT devices with different sensor. Sensor data will be collected by a Smart-Router, that aggregates and dispatches this data toward the SmartGateway that serves both monitoring and routing decisions, and which is consequently connected with company visibility platform.

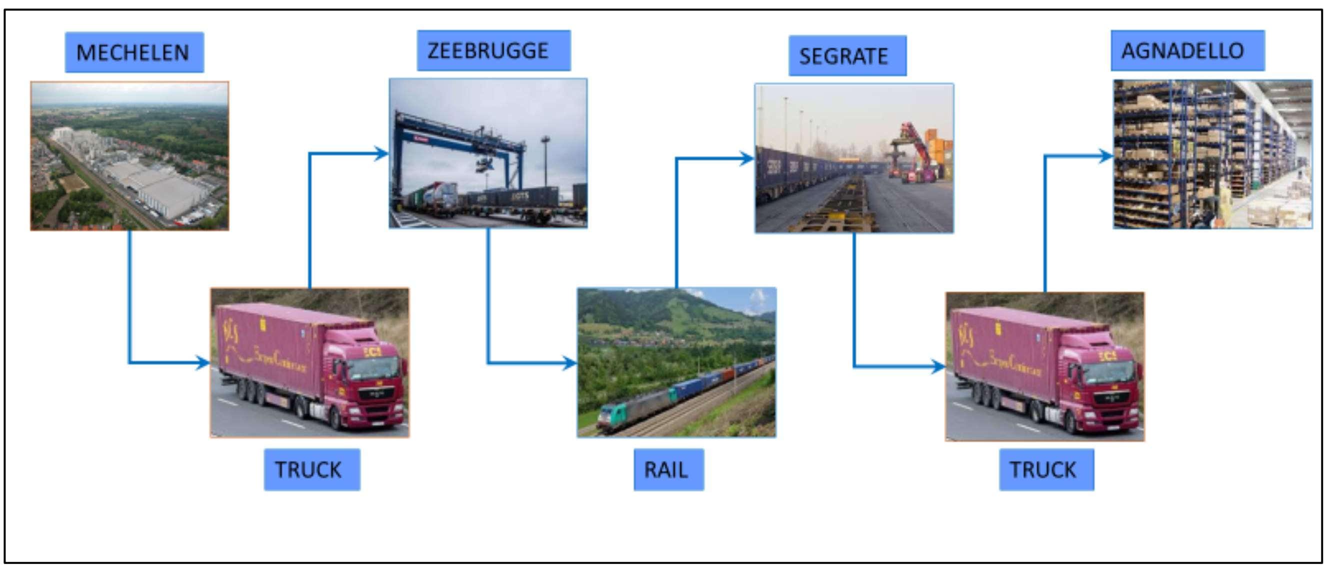


Figure 40: Mechelen to Agnadello Corridor

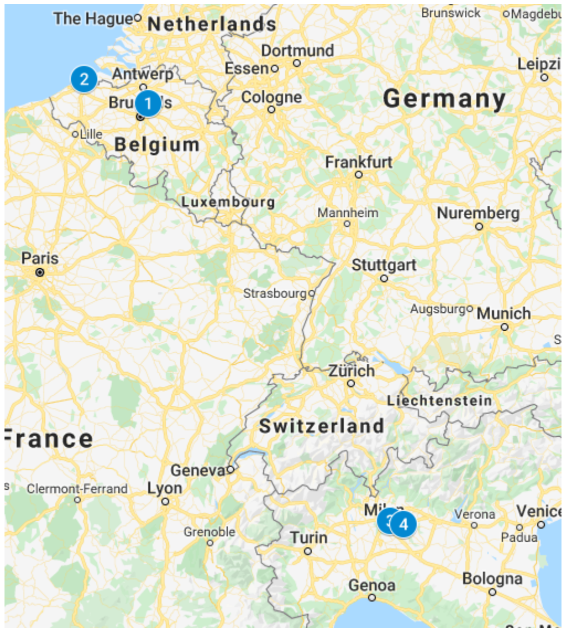


Figure 41: Mechelen to Agnadello Corridor

The objective of this simulation model is to evaluate the benefits of using cloud PI services for transport management in a long-distance corridor. The simulation model could be connected to different services like routing services, IoT services, and traffic congestion services to represent the behavior of the PI agents with this information. In the following image (Figure 42) there is the schematic representation between the simulation model and the Real World Containers through the PI cloud services.

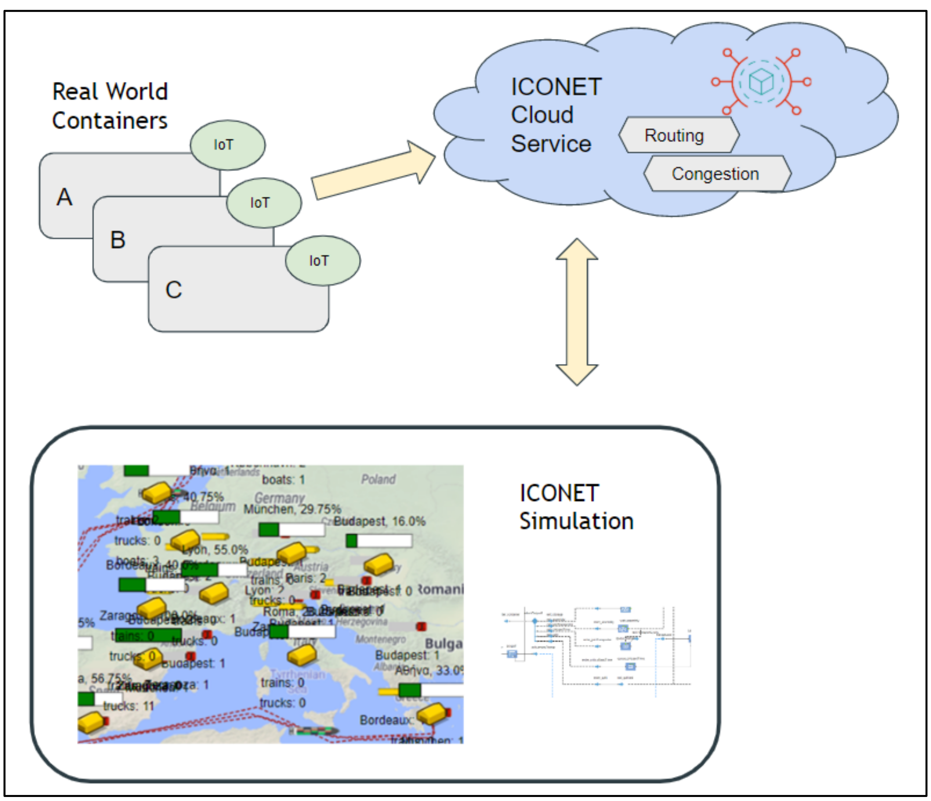


Figure 42: Schematic view of the connection between PI simulation and cloud services.

6.4.2.1 *Simulation Elements*

The principal elements of this Living Lab, according to the Generic PI Case Study framework are:

- PI Nodes
  - Source Node: node where container is injected to the network by the location service.
  - Network internal nodes: nodes where virtual container ask for the network status service and route can be re-evaluated.
  - Destination Node: Container final destination.
- PI Corridors
  - European road network
  - European rail network
- PI Roles
  - Sender
    - Factory
  - Receiver
    - Retailer warehouse
  - Transport
    - Truck, Train
  - Coordinator

6.4.2.2 *Cloud service: Routing*

In this living lab the containers must arrive from Mechelen (Belgium) to Agnadello (Italy). To reach their final destination, the containers follow different routes through PI-movers, which may refer to trains and trucks on this Living Lab. The route is dynamically calculated by PI Cloud Routing Service, which provides the best list of routed options prioritized. At the beginning of the trip, in the first PI node, the container asks the routing service for the complete journey. After that, during the journey in the PI network, when the PI-container arrives one next node, evaluates the congestion in the path to get the following node on its preferred route. If the PI-corridor is congested, PI-container will ask again to the PI-service for the best route from next possible nodes (preferably Level 1 nodes). Cloud routing service prioritize on higher-level nodes, which provides more the probability to find PI-movers and options to travel are higher.

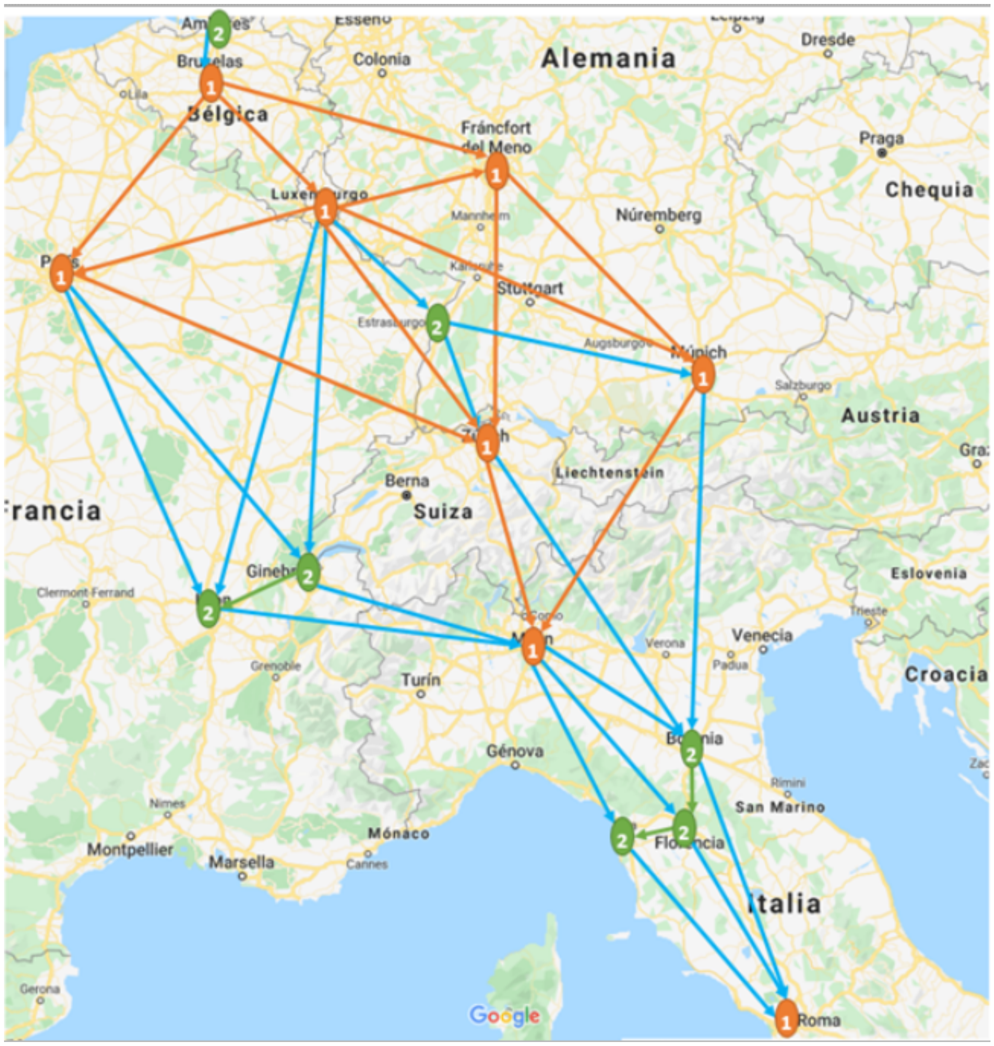


Figure 43: Geographical representation of the corridor network

In this case, the example of integration between the simulation and the IoT service is shown in the following diagram (Figure 44). The diagram represents the sequence of events starting from the moment the sender commences the container journey. The position of the container is updated through the IoT service. The service communicates with other PPI services, such as the shipping service and could send information to the simulation model in special events, like at node arrival, or when a delay from the actual plan appears. The simulation receives data form the IoT service, and It could ask for more information, if needed, to the PI services. From that moment on, the container moves through the network according to the logic and rules of PI. Iteratively, to analyze the scenario, it moves the container to the next node, asks for the best route, and evaluates possible network congestion. Finally, it returns the result of the main indicators to the user interface for analysis.

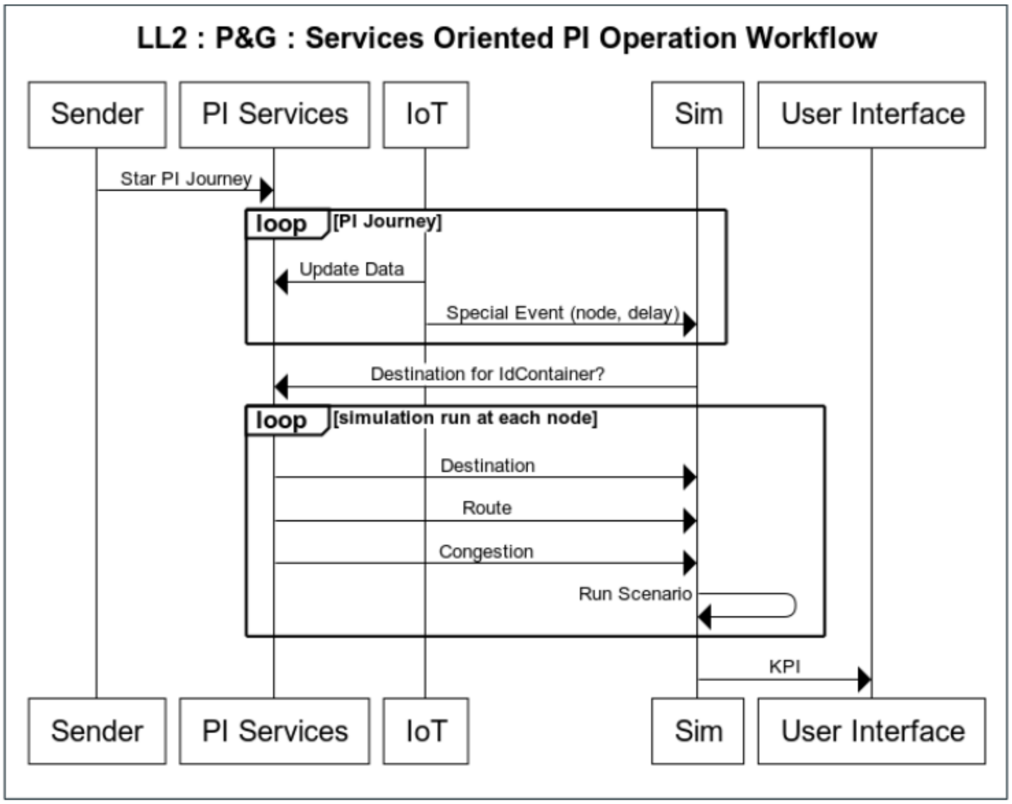


Figure 44: Integration services diagram

6.4.2.3 *Main KPI*

The anticipated improvements from this living lab consider a number of significant operational efficiencies measurable under the following KPIs:

1. Increased end-to-end cross transportation mode corridor visibility (visibility currently not available)
2. Increased efficiency within intermodal corridors allowing cost, service and inventory improvements (over 10% improvement versus non synchromodal state)
3. Increased reliability with intermodal corridors as a driver for synchromodality (over 10% improvement in meeting SLAs)
4. Improved corridor environmental performance (over 10% CO2 reduction)

The specific indicators used in this Living Lab for evaluating the performance of a European Corridor using the PI rules are the following:

- Impact on service level through using intermodal containers.
- Impact on transportation cost through using intermodal containers.
- Impact on inventory through using intermodal containers
- Impact on service level through alternative routing of intermodal containers.
- Impact on transportation cost through alternative routing of intermodal containers
- Impact on inventory through alternative routing of intermodal containers

- Impact on CO2 emissions of intermodal container.
- Calculation of Estimated Time of Arrival (ETA) to final destination of each container.

6.4.2.4 LL2 Sim V.1.1

The objective of this simulation model is to evaluate the impact of the application of the Physical Internet management rules on a European corridor. The European freight corridors are the backbone of the trans-European transport networks. Due to the increasing volume of freight, these corridors are occasionally in a state of saturation. Saturation may affect one section of the network or one transport node. The purpose of this simulation is to evaluate how congestion can affect the operation of a PI distribution network and how the different PI services may help to mitigate the effects of the congestion in the corridors.

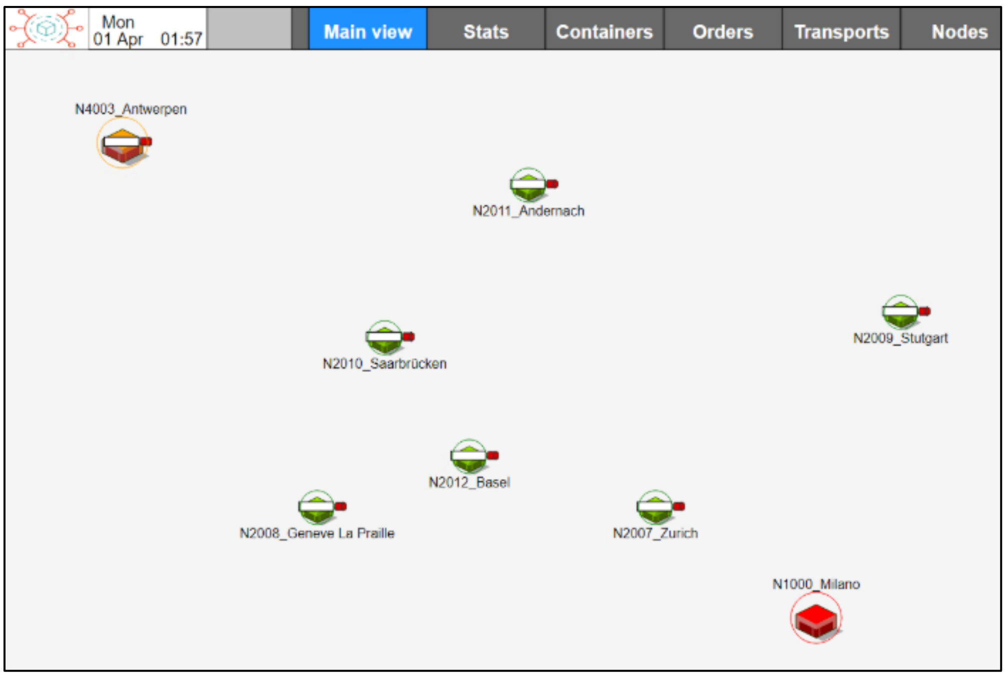


Figure 45: Initial simulation. Conceptual model.

The following figure (Figure 46) show the geographical representation of the Physical Internet Network of the corridors for this living lab.

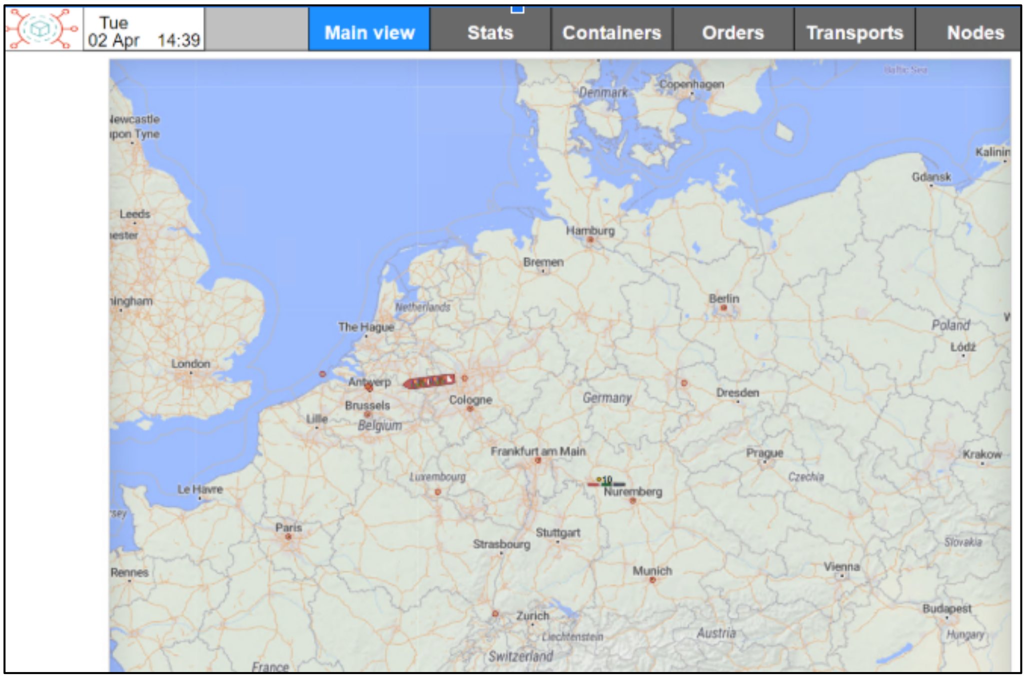


Figure 46: European corridor simulation model.

6.4.3 Simulation Scenarios

The main objective the simulation scenario is to evaluate the impact of using different intermodal options with different network conditions. The description of each scenario is in the following table (Table 13):

Table 18: Brief Description of each Scenario

	LL2 Scenario Description
E201.Road No Congestion	Transport limited to road vehicles **without** considering the congestion.
E202.Road Congestion	Transport limited to road vehicles considering the congestion in the links, or nodes.
E203 Intermodal No Congestion	Transport by rail or by road **without** considering the congestion.
E204Intermodal Congestion	Transport by rail or by road considering the congestion in the links, or nodes.

The first two scenarios (E201 and E202) are extreme conditions of the transport distribution network, forcing every container to be moved by road. The last two options represent the Physical Internet approach to the container delivery.

The simulation models are currently being evaluated and validated with the project partners. The results of the final application of the services and the simulation integrated with the real data will be shown in the WP3 deliverables with the tests performed.

6.4.4 IoT Cloud Service Integration

This section describes the model used for the integration of the simulation model with the IoT Cloud Services. A flexible simulation model has been created to identify different nodes and different types of containers. First a screen is presented (Figure 47) where the user can define the source node, destination node and one intermediate node. On this screen the user can also select the container identifier to be used.

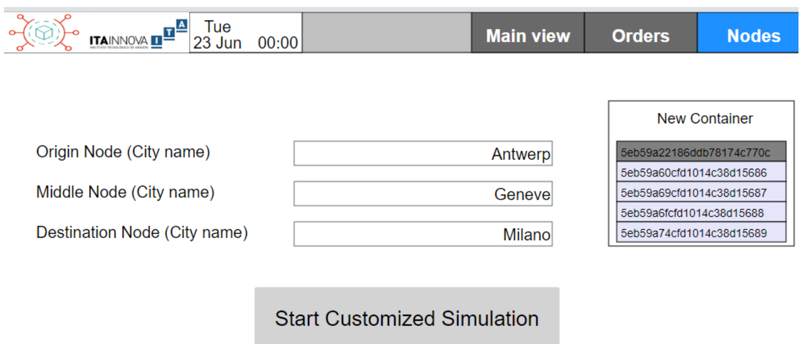


Figure 47: Node definition screen

In the main view, a map appears with the representation of the nodes that have been defined in the previous screen. By pressing the new container button, a new trip from the source node to the destination node is generated. In the lower part of the screen there is a display of the different messages sent from the simulation to the IoT Cloud Service and the answers obtained from the service.

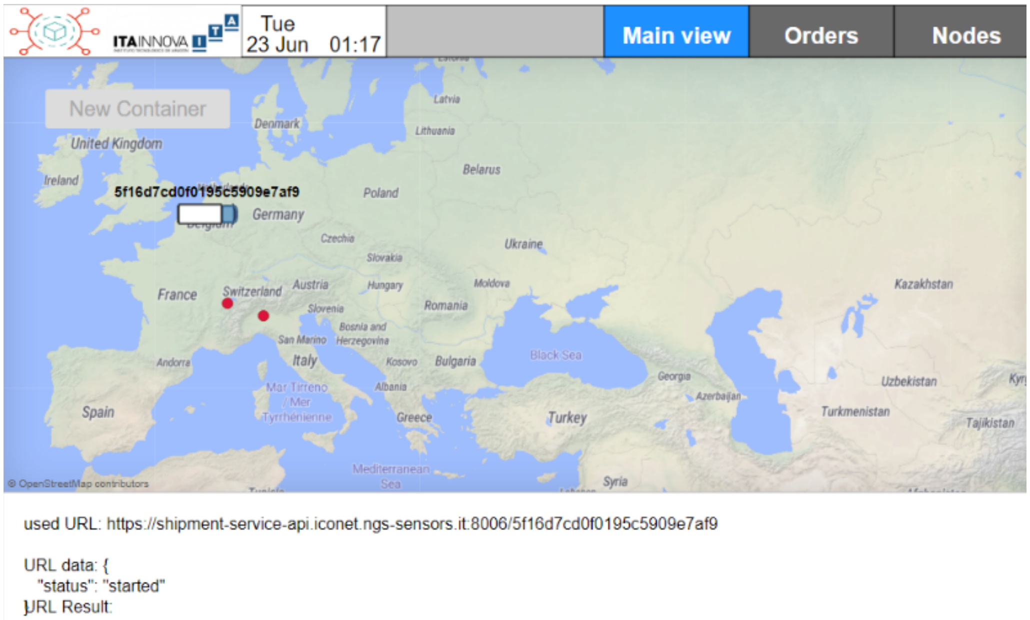
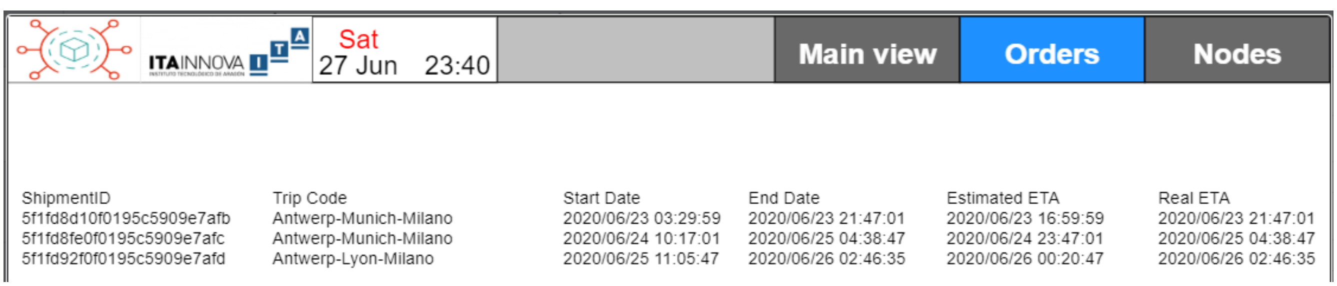


Figure 48: Simulation message view.

The simulation model can create different trips between different nodes for different orders. In the order screen, the elapsed time information is displayed for each container on its journey through the PI network, from the source node to the destination node. The model calculates the duration of the travel times and compares it with the initial estimated duration data. The following image (Figure 49) shows various examples of container journeys from Antwerp to Milan along different routes.



ShipmentID	Trip Code	Start Date	End Date	Estimated ETA	Real ETA
5f1fd8d10f0195c5909e7afb	Antwerp-Munich-Milano	2020/06/23 03:29:59	2020/06/23 21:47:01	2020/06/23 16:59:59	2020/06/23 21:47:01
5f1fd8fe0f0195c5909e7afc	Antwerp-Munich-Milano	2020/06/24 10:17:01	2020/06/25 04:38:47	2020/06/24 23:47:01	2020/06/25 04:38:47
5f1fd92f0f0195c5909e7afd	Antwerp-Lyon-Milano	2020/06/25 11:05:47	2020/06/26 02:46:35	2020/06/26 00:20:47	2020/06/26 02:46:35

Figure 49: Main information from orders ETA in simulation model.

During the container's journey in the simulation, the virtual tracker periodically sends information to the IoT Cloud service. The following image (Figure 50) shows the message sent by the tracker identifying the container the day, the time, latitude and longitude among other fields.

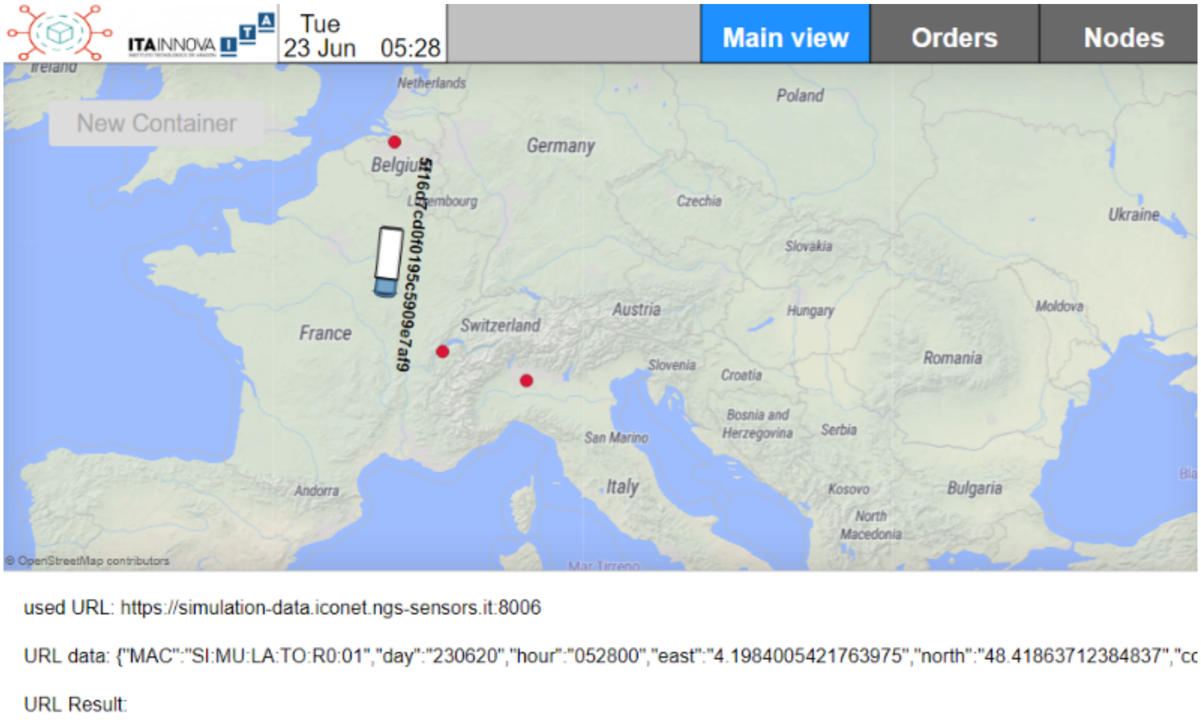


Figure 50: Example from messages exchanged with IoT cloud during PI Journey.

The information sent from the simulation model is collected in the IoT cloud service application. The following image (Figure 51) shows a map that reflects the test sent position of the virtual tracker. Each point on the map corresponds to a position sent from the simulation model. The picture shows a combined trip from Denmark to the Ukraine and finally to Italy.

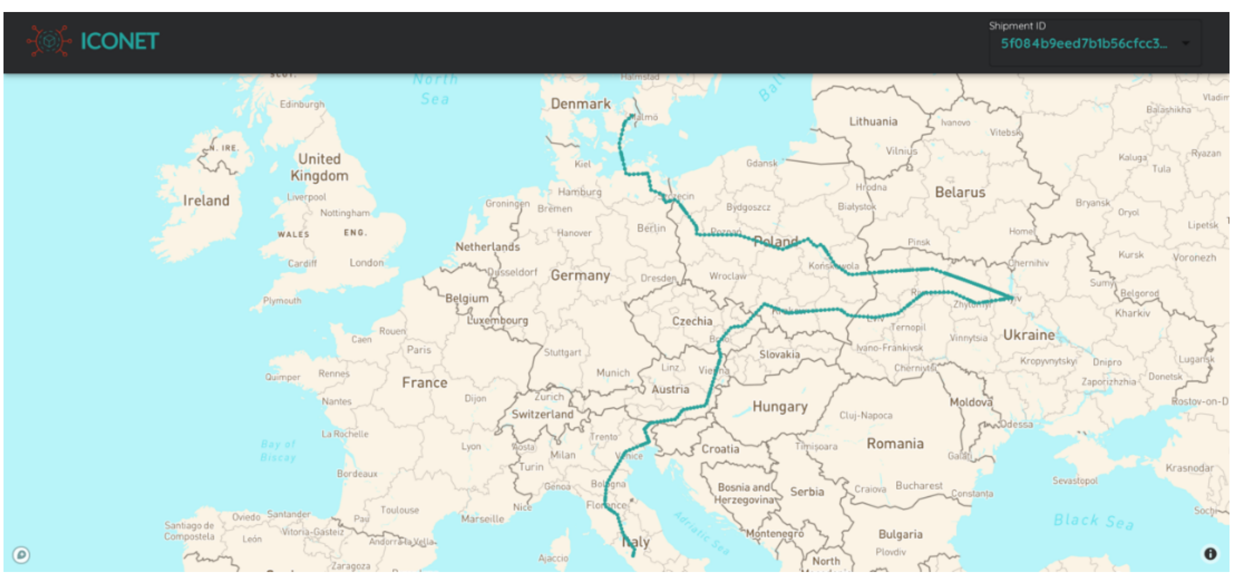


Figure 51: Example of tracker journey.

Inside the IoT Cloud Service it is possible to obtain different reports with the information collected with the simulated Tracker. For example, the following image (Figure 52) shows the different speed values obtained in the simulation in different sections.

Figure 52: Example of IoT tracker measures evolution.

6.4.5 Blockchain Service Integration

The blockchain service allows secure, immutable storage of information generated on the physical Internet network. The model allows to test the blockchain operation when the containers pass through the different nodes of the physical Internet network. The following image (Figure 53) shows the information fields that are recorded in the block chain through a Smart contract. Elements such as the origin and destination of the container or the temperature levels required for the handling and transport of the product are recorded.

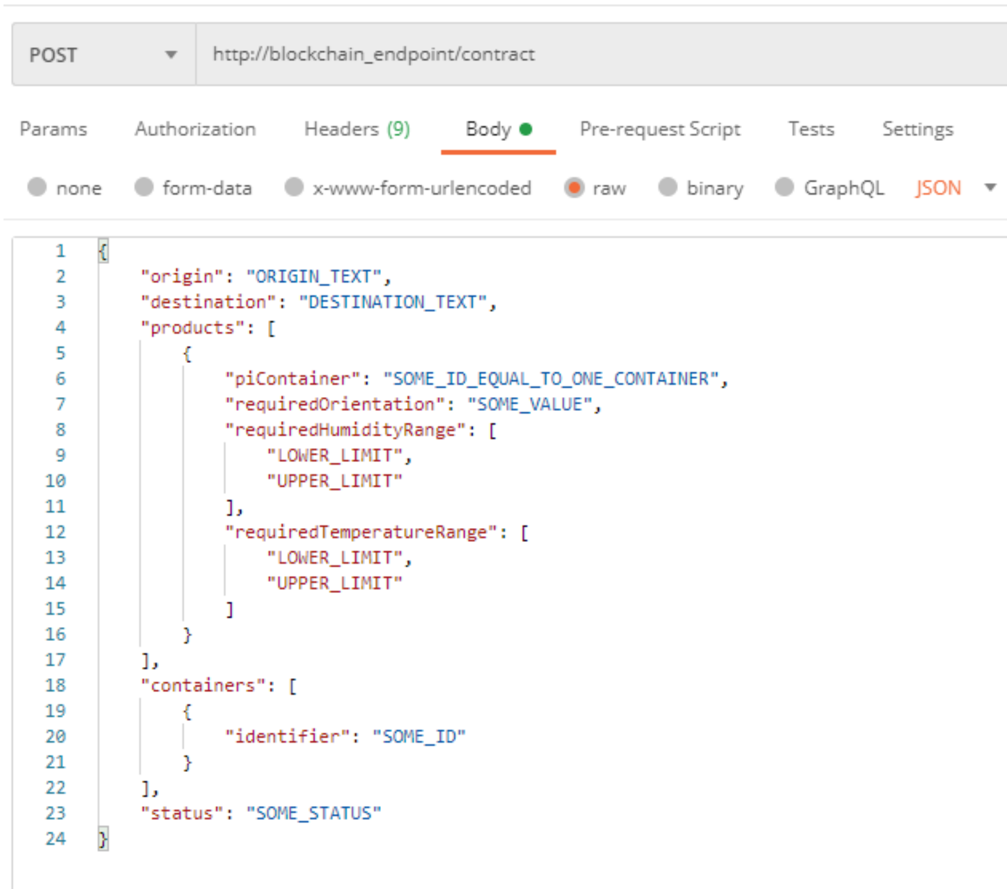


Figure 53: Example of Blockchain service message structure.

After communicating the information from the simulation model to the blockchain service, the service returns the hash of the transaction where all this information has been recorded within a blockchain block

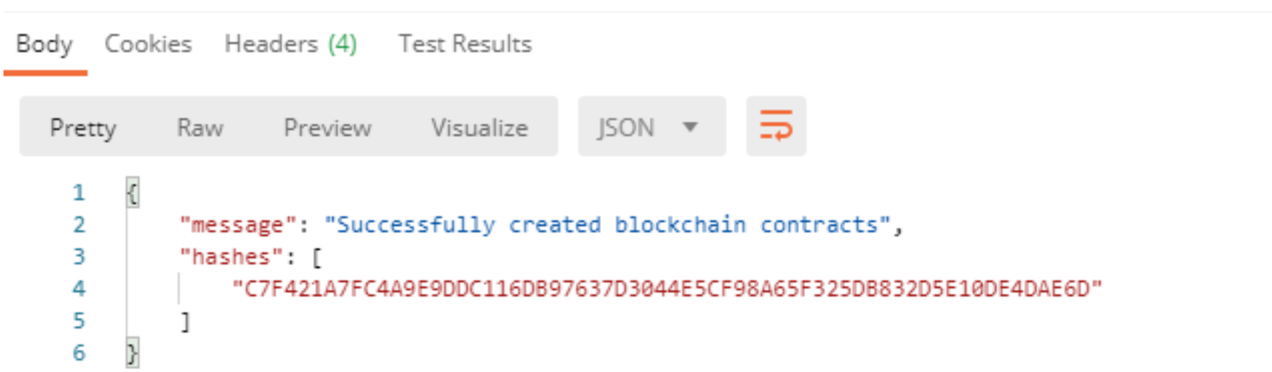


Figure 54: Example of Blockchain service response.

6.4.6 Networking and Routing Service Integration

The Networking service provides information on the characteristics of the network components. One of the main points is the definition of the network nodes. The following image (Figure 55) shows the basic configuration of the representation of a node, with the attributes of identifier, name, latitude, longitude and level.

```
/**
 * Json_Nodes
 */
public class Json_Nodes implements Serializable {

    public int [] nodeid;

    public String [] nodename;

    public float [] nodelat;

    public float [] nodelong;

    public int [] nodelvl;

    //public String [] node_type;

    /**
     * Default constructor
     */
    public Json_Nodes() {
    }

    /**
     * Constructor initializing the fields
     */
    public Json_Nodes(int [] node_id, String [] nodename, float [] nodel
        this.nodeid = nodeid;
        this.nodename = nodename;
        this.nodelat = nodelat;
        this.nodelong = nodelong;
        this.nodelvl = nodelvl;
        //this.node_type = node_type;
    }
```

Figure 55: Example on node data information structure.

Starting from the information of the nodes, the graphic representation of the network is built as shows the following image (Figure 56). The Routing service also uses these nodes to create the best route, according to different configuration parameters (minimum distance, best time...). The description of the operation of these services in more detail can be found in other documents such as D2.14 'PI networking routing shipping and encapsulation layer algorithms and services'.

```json
{
    "modes": [
        0,
        1,
        0,
        1,
        0,
        2
    ],
    "nodelist": [
        56,
        55,
        38,
        42,
        64,
        91,
        1
    ],
    "nodenames": [
        "Brussels",
        "Luxembourg",
        "Metz",
        "Strasbourg",
        "Basel",
        "Milan",
        "P&G AGNADELLO "
    ],
    "totalCost": 2190.0
}
```

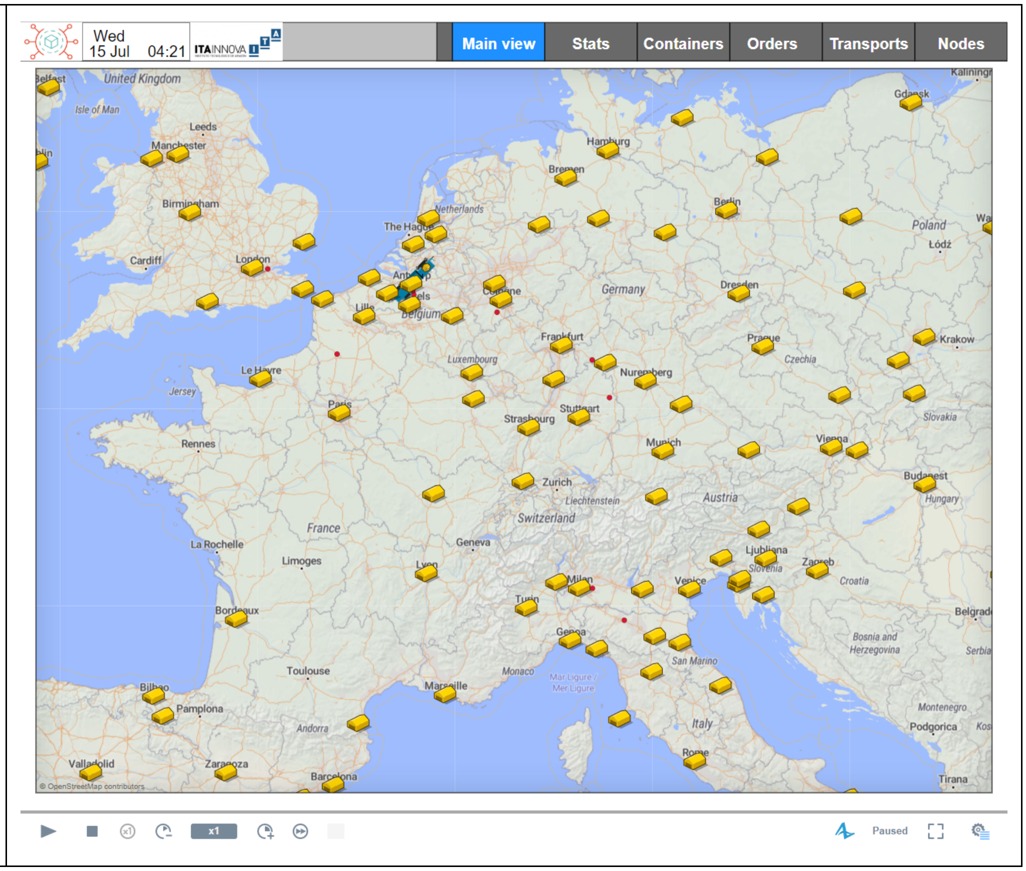



Figure 56: Example Routing Route and GIS representation.

7 Conclusions

The movement of products and transport within the Physical Internet network has a complex dynamic behaviour. Various simulation techniques have been and continue to be engaged to represent these dynamic effects. The main advantages of these techniques are transparency, visualization, interaction and capability for creating deeper knowledge and understanding of the relevant processes. As part of the project, a simulation methodology has been defined to evaluate and compare different scenarios, taking into account both real data feeds by the living labs, as well as, new PI behaviour rules. As the project progresses, those models are expected to integrate with real data feeds, representing the physical dimension of the living labs.

In the project, different types of simulations models have been developed. For each model, multiple different versions have been formalized through the validation process followed with the involved project partners. All the simulation models are based on real data from the living labs, provided by companies involved in the project. As for the GPICS simulation model, data come from the Eurostat official transport statistics between the NUTS2 regions.

The digital simulation models of different supply networks have been developed. Following validation sessions with the project's business partners, improvements such as modifying dynamic procurement rules, or updating costing metrics have been made. The results of digital simulations indicate that different type of benefits (operational, economic and environmental) could be achieved when PI concepts are applied to different business scenarios. From an operational point of view, the simulation shows that it is possible increment of the fill rate of the transport, while maintaining the current level of service, or even it can increase in some cases. From an economic point of view the solution succeeds because it reduces transport costs while maintaining preparation costs. In some scenario savings of about a 10% in the fulfilment costs. Finally, from an environmental point of view, it also achieves a significant reduction in CO2 emissions.

The simulation developed is a tool that helps companies to visualize how the movement of products over a PI network can be, including flows from other companies. The simulation allows to validate the operation of the services (networking, routing, encapsulation and shipping services) developed for the operation of Physical Internet.

The description of the models used for the physical PI simulations and the interaction with the services have been included. These simulation models have the capacity of being integrated with different physical internet services to run real data scenarios. The simulation models have been defined and developed.

The integration with the different services is coming in the living labs testing phase. The simulation models developed with the project partners are currently being evaluated and validated. The final results of the impact of the implementation of the services to the living labs will be included in the final reports of Work Package 3, at the end of the project.

This report concludes the series of deliverable reports initiated with D2.15 submitted back in M7. As stated above the role of the simulation modelling in ICONET project is the actual testing tool of the offering of the designed PI services. The simulation environment was co-designed in collaboration with LL leaders, users, and stakeholders to ensure relevance of the solutions designed to the Supply Chain realities of today and with an outlook for the future. It also provides a platform for users to experiment and witness the potential PI can offer thus illustrating the capabilities of the concepts of the PI network. Beyond the current report, the simulation work will continue with the work of the LLs till the very end of the project.

• 8 References

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Annex

Annex 1: GPIC Simulation model evolution

This model will contain a general representation of the main nodes, or hubs, and their interconnections. According to the elements defined in T1.5. (T1.5 Generic PI case study for linking the long-distance network with urban areas), in the GPICS and the elements described in section 3.2 of this document.

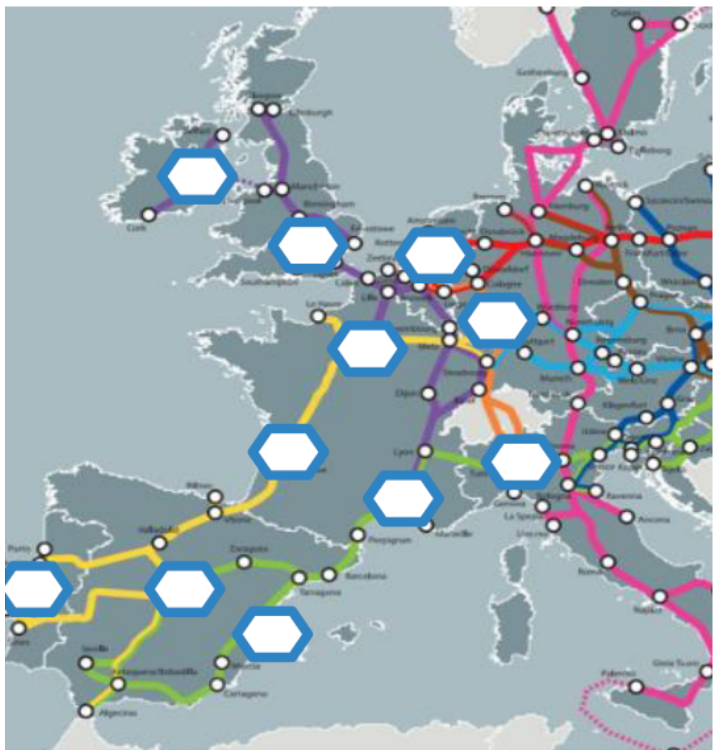

Figure 57: Preliminary concept from the European GPIC network simulation.

This model creates a representation of the main flows of freights in a PI network. It can include transports from different companies, with different restrictions. The main advantage is that the model measures several indicators (operational, economic, and environmental) over the same scenarios. In the ICONET project, this model will be used mainly to assist in the evaluation of the GPICS performance and the definition of the Hub Plan.

The concept of GPICS is evolving throughout the life of the project, as progress is made in the different aspects of the research. In the following paragraphs we are describing the evolution in the simulation developed with the validation of different concepts.

GPIC Sim V.0.3

The objective of third version of the GPICS simulation model is to increment the complexity in the behaviour of the transporters. At this point, the concept of orders and container are also included for validation at this step.

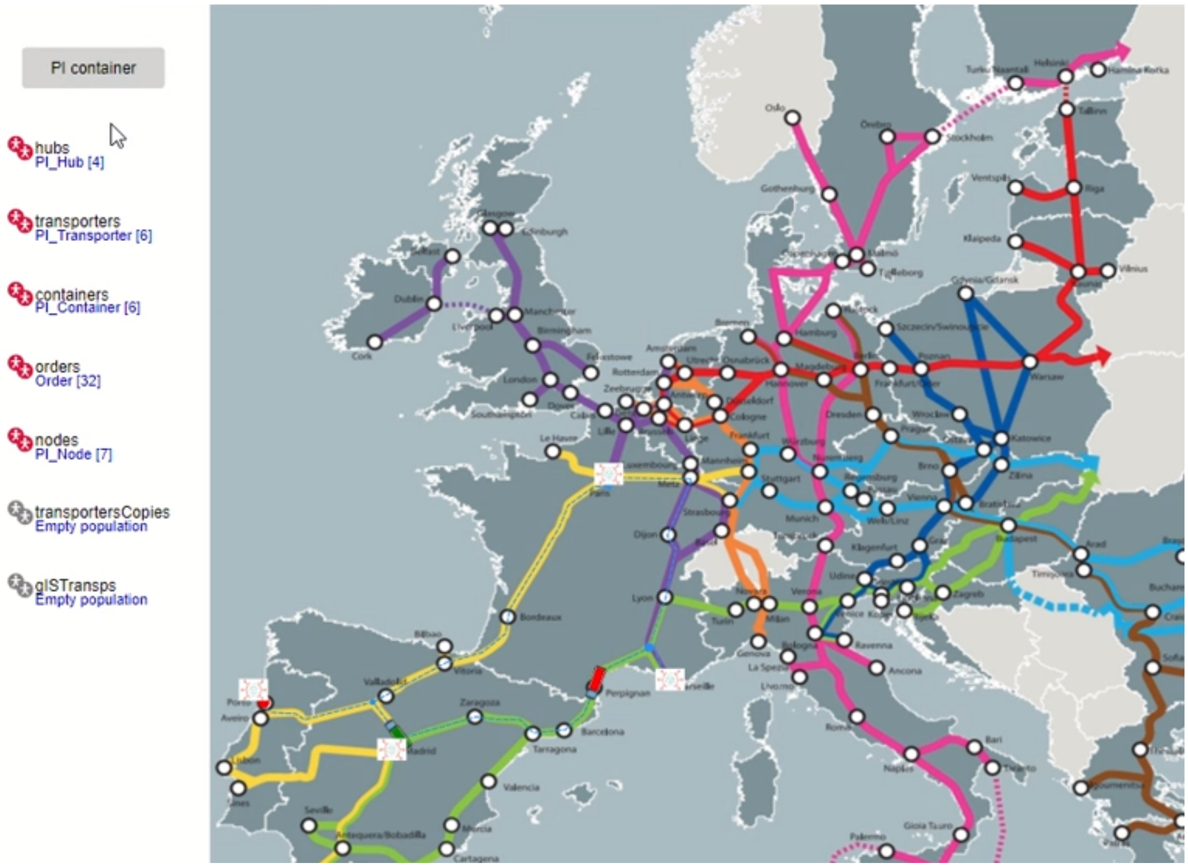

Figure 58: Representation from GPICS Sim V.0.3.

In this model the behaviour from transporters, nodes and containers are integrated. The behaviour from the generic node is described in the section 3.2.4 from this document, and it is represented in the image Figure 59. This image also includes the state diagram used to model the behaviour from a transport (right side of the image).

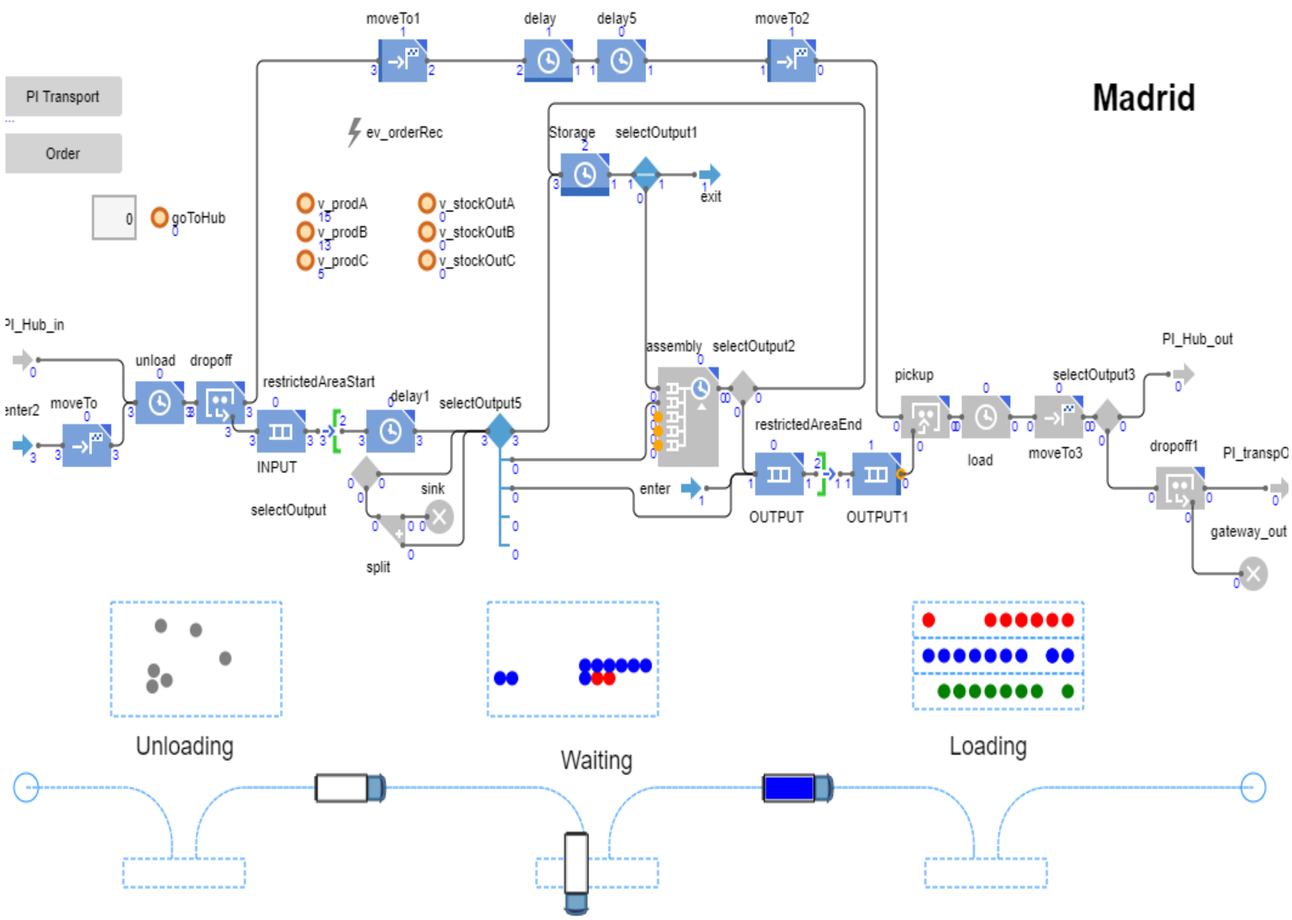

Figure 59: Internal representation of the behaviour of a node and the status diagram from a transport.

Simulation Scenarios

This section describes the main simulation parameters and the respective variance levels, based upon which we will configure the behaviour of the PI simulation model. Most of these options are further analysed in the deliverable D1.7 Generic PI Case Study and the associated PI Hubs Plan.

Scenario Options

In this scenario from the GPICS we have evaluated the influence of the transport policies under the PI framework. There are two transport modes:

- **Scenario 1001: Direct transport**. The transportation between the nodes is made directly with a dedicated transport. This case represents transport as-is in most cases, cargos are shipped from A to B and all transports belongs to the company.
- **Scenario 1002: Transport through GPICS node**. In this case, the transportation is made through the GPICS network, with the PI transporters and the PI nodes. According to GPICS definition, nodes are classified in layers hierarchically. Layer 1 contains biggest hubs. Communications among layer 1 hubs is very fluent. Layer 1 hubs are connected to several layer 2 hubs. Layer 2 hubs are connected to the rest of layer 2 hubs in the same layer 1 hub, but a container can't travel among 2 hubs of layer 2 which belong to different layer 1 hubs. Containers have to "climb" to nearer layer 1 hub before they can change layer 1 hub. Same to layer 3 hubs. There can be exceptions when 2 hubs are close, although they belong to different "father-hubs". Other companies are considered, so there's a percentage of the filling rate which corresponds to them.

One example of this scenario is the following. One sender needs to move a pallet from Oporto to Marseille. In the first scenario (1001), the user sends directly the pallet form Oporto to Marseille. The user hires a transport from Oporto to Marseille. In the second scenario (1002), according to the GPICS rules, the user sends the pallet through the PI network. Oporto is a PI-node of level 2. Its corresponding level 1 node is Lisbon. After that the pallet moves to Paris. And finally, from Paris to Marseille.

Simulation results

The following figures contain the results from the simulation of the different scenarios. The first figure (Figure 60) shows the main operational KPI. The total distance travelled by the transporters in the scenario and the mean utilization of the truck, and the mean fill rate. The total distance travelled in the first scenario, transport direct, is higher than the second scenario (GPIC v1). Due to the consolidation of loads, the number of movers is reduced, so the total distance decreases and the fill rate grows.

idScenario	desScenario	Total distance	Mean fill rate

1001	Transport Direct	22'601'093	34%
1002	GPIC v1	20'143'410	48%

Figure 60 Operational KPI.

From an economic point of view, in the GPIC v1 scenario, the transport cost is lower than the transport direct scenario. On the other hand, the handling cost is higher in the GPICS scenario, there are additional handling steps in the intermediate nodes. Also, some storage cost is required in the GPIC scenario. Consequently, the total cost in the GPIC v1 scenario (1.597.967 €) is slightly higher than the direct transport scenario (1.502.300 €).

idScenario	desScenario	Transport Cost	Handling Costs	Storage Costs	Total costs
1001	Transport Direct	1'201'640 €	300'660 €	0 €	1'502'300€
1002	GPIC v1	906'055 €	609'083 €	76'829 €	1'591'967 €

Figure 61: Economical KPI.

Additionally, from the environmental point of view, the emissions in the GPICS scenario are lower than the transport direct scenario. The reduction is 11%, is directly correlated with the distance travelled in each scenario.

idScenario	desScenario	Total CO2
1001	Transport Direct	11'300'547
1002	GPIC v1	10'071'705

Figure 62: Environmental KPI.

Annex 2 : LL3 Previous simulation results

The simulation model for Living Lab 3 is composed by 3 suppliers, 1 dark-store, 9 stores and 27 clients arranged in 3 zones. Each store will serve 3 clients under its influence area. In centralized scenarios, all the orders are prepared in the dark-store and suppliers, supply the dark-store. On the other side, in store preparation means that the orders are prepared in the stores, so suppliers send the goods directly to them, instead of feeding the system through the dark-store. Three delivery modes have been considered. Home delivery means that the order has to be sent to the client's home. Click-and-collect is for clients who prefer to pick their order at the store, instead of their own home. The 3rd party pick-up point is similar to the click and collect, but the picking takes place in another location, not in a store.

Scenario Options

The main objective from this LL is to evaluate different preparation and delivery strategies for eCommerce distribution. The main variables involved are shown in the following Table 19).

Table 19: Main LL variables

	Scenario variables
Preparation process	• (CEN)Centralized

	• (INS)In-Store (small or large)
Delivery Option	• (HMD)Home delivery • (CLC)Click&Collect • (3PP)3rd party pick-up-point

With the combination of these variables, we can obtain 6 scenarios: 2 values from the preparation process x 3 values from delivery option. The description of the combination of the variables could be shown in the following image (Figure 63).

Scenario	Preparation	Delivery
301	CEN	HMD
302	CEN	CLC
303	CEN	3PP
304	INS	HMD
305	INS	CLC
306	INS	3PP

Figure 63: LL3 scenario definition.

The description of each scenario is in the following table, Table 20:

Table 20: Brief Description of each Scenario

	LL3 Scenario Description
301 CEN-HMD	There are 27 orders to serve to clients and 3 weekly replenishments orders from the dark-store. Each supplier sends a transporter to the dark-store. From the dark-store to clients, each transport covers a client's zone in a milk run kind route.
302 CEN-CLC	Same 27 orders have to be served, but in this time they will be picked in stores, so instead of deliver the orders at home, transporters will deliver the orders to the more convenient store for the client.
303 CEN-3PP	The 3rd party pick-up point is similar to the click and collect, but the picking takes place in another location, not in a store.
304 INS-HMD	Preparation in a store. This scenario requires a bigger transporter fleet for the home delivery to cover effectively the whole area. Stores need a daily replenishment in order to be able to serve the orders considered.
305 INS-CLC	Preparation in a store. The click-and-collect scenario needs fewer transporters than the home delivery scenario. That can be seen in the general results, especially in delivery costs and total distance.
306 INS-3PP	Preparation in a store. The 3rd party pick-up point is similar to the click and collect, but the picking takes place in another location, not in a store.

Scenario orders

In this LL, orders are related with e-commerce orders placed by clients during a one year period. The same orders could be prepared in a different location and delivered in several modes.

The orders used in this simulation are based on historical data from the company in the year 2018. The data is recorded on a daily basis and grouped at postal code level, show in Figure 64 For scenario benchmarking, the same group of orders is used in the entire scenario configuration. The duration of the scenario is 4 weeks.

cp4	CP7	InvoiceDate	Ship Coun
4000	4000-008	2018-01-20	1
4000	4000-008	2018-03-10	1
4000	4000-008	2018-04-13	1
4000	4000-008	2018-08-18	1
4000	4000-008	2018-09-14	1
4000	4000-008	2018-10-15	1
4000	4000-008	2018-12-12	1
4000	4000-010	2018-04-14	1

Figure 64: Data Source for simulation orders.

Simulation Results

The following figures contain the results from the simulation of the different scenarios. The first image (Figure 65) shows the main KPI from the different scenarios. Regarding the distance travelled in the scenarios the minimal distance is obtained in the scenario 302, in this scenario, the preparation is in the store and the delivery is made with the option Click and collect, the customer comes to the store to take the orders. The mean utilization of transport is also high in this case up to 49%. The worst scenario, in this case, is the 301 preparation centralized and home delivery option. The total distance travelled is 911.940 Km. in four weeks, and the mean utilization is low due to the high number of empty returns.

idScenario	desScenario	Total distance (km)	Total stock outs	Mean fill rate
301	CEN-HMD	911'940	0	7%
302	CEN-CLC	35'915	0	49%
303	CEN-3PP	322'680	0	19%
304	INS-HMD	134'735	0	6%
305	INS-CLC	41'405	0	27%
306	INS-3PP	85'325	0	27%

Figure 65: Operational KPI in LL3

Regarding the economical KPI (Figure 66), considering the transport cost and the preparation cost, the best scenario is also the 302. This scenario has reduced value in the transportation cost and also in the preparation cost.

idScenario	desScenario	Transport Cost	Preparation cost	Total costs
301	CEN-HMD	18'151 €	1'459 €	49'610 €
302	CEN-CLC	2'348 €	1'062 €	3'409 €
303	CEN-3PP	18'183 €	1'459 €	49'642 €
304	INS-HMD	4'420 €	14'030 €	18'450 €
305	INS-CLC	2'348 €	14'030 €	16'378 €
306	INS-3PP	5'534 €	14'030 €	19'564 €

Figure 66: Economical KPI in LL3

From the environmental point of view, the higher quantity of emission is achieved when the preparation is centralized and the delivery is made to the house of the client. The minimum number of emissions is obtained in scenario 302, where the preparation is centralized and the customer comes to the store to take the orders. There are also low rates of emission in scenario 305, 306 where the preparation is in the store and the client takes the order in the store (305) or takes the order in the third party pick-up-point.

idScenario	desScenario	Total CO2 (gr)
301	CEN-HMD	455'970
302	CEN-CLC	17'958
303	CEN-3PP	161'340
304	INS-HMD	67'368
305	INS-CLC	20'703
306	INS-3PP	42'663

Figure 67: Environmental KPI in LL3

Annex 3 : LL4 Previous simulation results

Living Lab 4 (Stockbooking) will offer more storage possibilities to optimize trucks and reduce the transport cost and the CO^2 emissions. With the simulation model, we will obtain precise solutions, but we can explain the objective with a simple example: 10 pallets of a client A will arrive in Lille (North of France) and have to be deliver in Perpignan (close to the Spanish border) where consumers are 3 major options are possible:

- Store the product at the arrival point (Lille) and transport the 10 pallets directly when the client needs it. With this solution the handling cost is minimum because you only load and unload the truck and the warehouse one time but the transport is expensive. You will pay for a dedicated truck of 33 pallets but use it only for 10 pallets.
- Directly transport the 10 pallets near Perpignan and store it near the customer until they need the products. Same result as the situation before. You only switch the order but use the same services.
- Optimize the transport adding some stops on the way to combine clients transport and reduce the transport cost. The handling cost will be higher because the pallets will be manipulated several times. But adding stops in different locations (warehouse) will offer you the possibility to optimize the transport by fulfilling the trucks of 33 pallets from different clients which will reduce the cost. In this example you could imagine a stop in Paris, maybe another one close to Lyon and a last one close to Montpellier. With this solution you capture some flux from Lille to Paris to empty the truck. The same between Paris and Lyon and between Lyon to Montpellier.

Simulation Model

In this business case the simulation network is country level. It includes a group of warehouses around the country of France and the transport network used to move the freight between them. The container level reference from this living lab is the pallet.

Simulation Elements

The principal elements of this LL, according to the Generic PI Case Study framework are:

- PI Nodes
    - Central Warehouse
    - Regional Warehouse
    - Stores (clients)
- PI Corridors
    - Truck (inter-city)
- PI Roles
    - Sender
        - Clients
    - Receiver
        - Clients
    - Transport
        - Truck
    - Coordinator
        - SB

Link to the PI Services

In future version of this Living Lab simulation the main PI services that are integrated with the simulation model are the following:

- **Service1: Capacity booking online.** Service to obtain the capacity of each warehouse in real time to simulate near future scenarios.
- **Service2: Choose the best warehouse**. According to a set of loads with origin and destination defined. This service will also call service 1 to evaluate the capacity online.

The connection with the real cloud services is part of the physical simulation (chapter 6 of this document).

LL4 Sim V.1.1

The second version of this model includes the network layers proposed in the GPICS. In these definitions the nodes are grouped in layers. Each layer has some specific characteristics. In this case the layer1 (Figure 68) contains the initial point of the network in this scenario, which are the ports. The second layer represents the main distribution nodes in the network. In the example, in the layer 2 there is one node in Paris and another node in Toulouse. The third layer in this case corresponds to the different regional warehouses and the fourth layer represents the final customers. All layers are connected with transports, between the layers and also from different nodes in the same layer.

The simulation model is composed by 4 ports which supply the goods, 1 central warehouse (located in Paris), 3 regional warehouses and 17 clients. Each regional warehouse will serve the clients under its influence area. LL4 scenario simulations last 15 days. The main flow in this scenario is that the central warehouse receives pallets from 4 ports every two days. The transport between the central node and regional nodes is made every three days and clients ask their goods every five days. The company has two options to serve its customers.

On the one hand, it can directly send the goods to the clients directly from the central warehouse. The cost of transport used will be quite expensive, due to the long distances trucks have to go through to reach their destinations, but handling cost is reduced, and is an easier way to manage all the orders. In this simulation there are 4 trucks covering the port-Paris routes every two days and 17 trucks among Paris-clients every three days. These trucks transport more than 400 pallets among the 25 nodes.

On the other hand, aligned to PI concept, the company could use a distributed strategy to create a network of warehouses on where they can store the pallets nearer to the final customer. This scenario contains the same number of pallets, but there are more trucks, because they need to connect central warehouse with the regional warehouses, which means there is a total of 24 trucks.

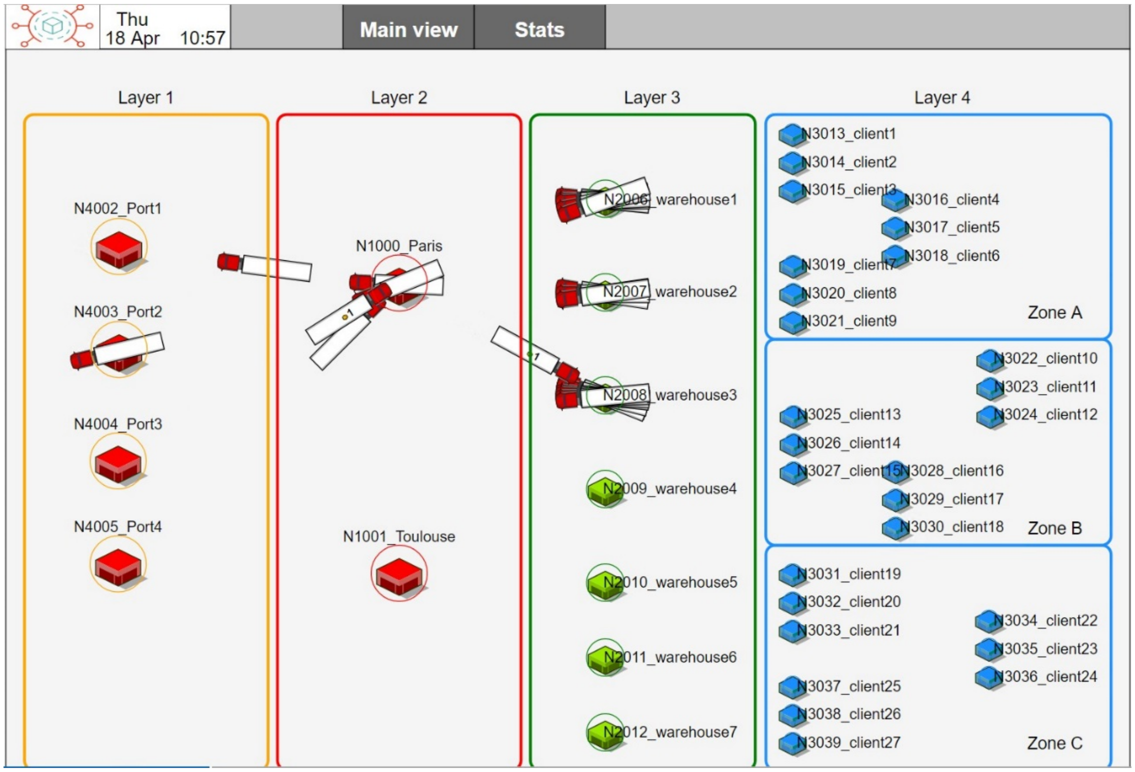

Figure 68: Simulation model network representation for LL4.

Transport frequency description:

Scenario	Layer 1->2	Layer 2->3	Layer 3->4	Description
401. Storage Central	Each 7 days (Weekly)	1d (daily)	1d (daily)	Storage at central Warehouse. CrossDocking at Regional Warehouses.
402. Storage Regional	Each 7 days (Weekly)	Each 7 days (Weekly)	1d (daily)	Storage at regional warehouses. CrossDocking at Central Warehouse (from ports)

Figure 69 shows the representation of the main indicators of the performance from a node in the distribution network. The graph shows the evolution of the stock from different products and the available storage capacity.

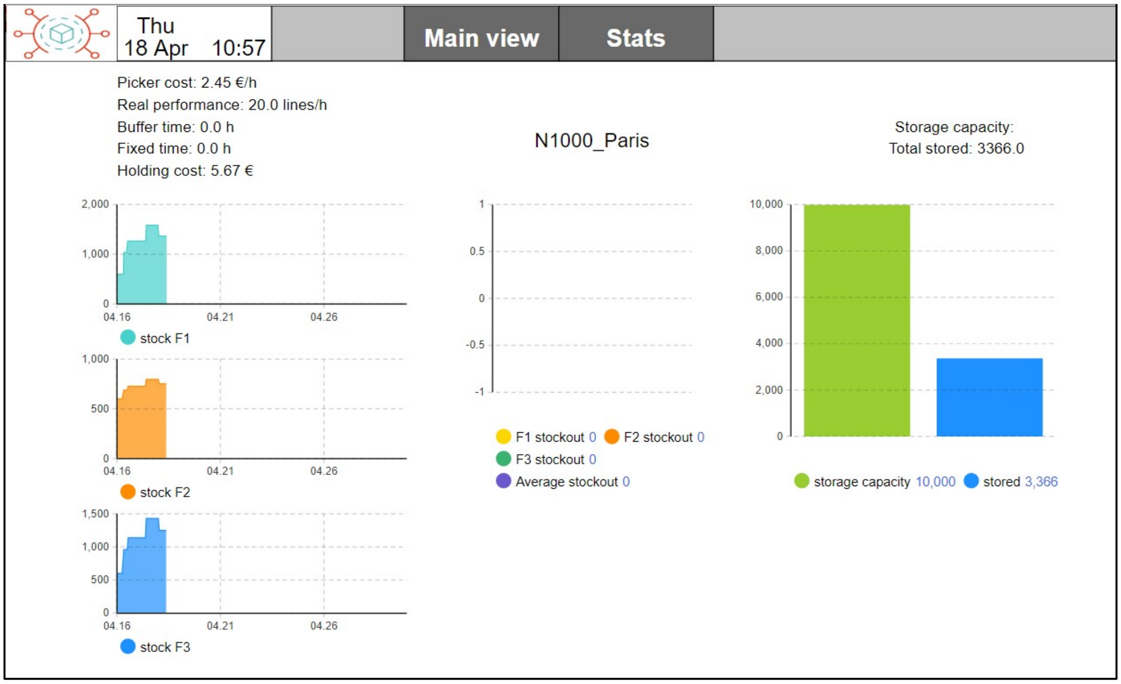

Figure 69: Detail of node KPI in the simulation model for LL4.

Simulation Scenarios

This Living Lab has two main dimensions to evaluate, the storage strategy and the transport strategy. Both dimensions have two options. In the storage strategy the options are centralized distribution and regional distribution in centralized scenarios, all the containers are stored in the central warehouse and then delivered to the clients. Balanced scenarios can store the containers nearer to its final client.

In the transport strategy, there are also two routing modes: Direct routes and milk run routes. The first option corresponds to the direct transport between nodes and the second option, the milk run, refers to the strategy to collecting pallets in one point to multiple destinations.

Scenario Options

One of the key points of this living lab is the capacity to select the best warehouse to store some products according to different factors (i.e. economics, service level or environmental). To evaluate the influence of this decision we have created two scenarios. The first one is based in a centred distribution model, with one central warehouse. According to the GPICS definition, at the level 1. In the second scenario there is a regional network of warehouses and the storage function is made at the regional level. The main details from each scenario are described in the following table.

Table 21: Brief description from each scenario in LL4.

	LL3 Scenario Description

401 CENTER	There are 17 clients, who ask every 5 days. In order to fulfil the orders, goods have to reach the company facilities (warehouses) some days before. In centralized scenario, all the orders are stored in the central warehouse and have a high cost of transport, due to the longer distances. There are 4 transports which supply the warehouse from the ports every 2 days and there is one transport per client every 3 days.
402 REGIONAL	The same 17 clients with the same orders. In this scenario, goods come from the ports to the central warehouse and from there, they are delivered into regional warehouses. Shorter distances to clients allow lower transport costs. There are 4 transports which supply the central warehouse from the ports every 2 days and one transport per regional warehouse every 2 days, in addition to the transport per client every 2 days.

Scenario Orders

In this LL the orders come from different clients from different sectors. They require distribution services, including temporal storage in some of the network warehouse.

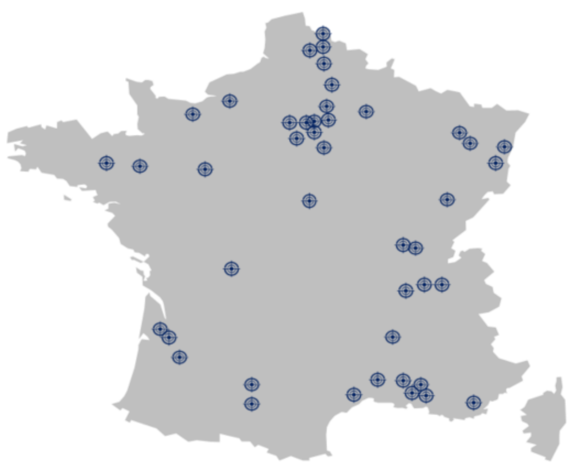

Figure 70: Map with Sender/Receivers in the LL3.

The orders used in the scenario represents the movements of real pallets in the network. The data used come from real transport records from a representative group of clients. As shown in the relevant figure**Error! Reference source not found.**, the orders are based on the transportation data from January 2019, with origin, destination and number of pallets.

Simulation Results

The following table contains the indicators obtained from the simulation model with the different scenarios. The indicators are grouped in three categories: operational, economic and environmental. Regarding the two scenarios, from the operational point of view (Figure 71) the total distance in the second scenario, regional distribution, is higher than the centralized scenario. Although in both scenarios the same number of products are moved, in the second scenario the filling rate is higher. The capacity of the transports in the regional distribution is lower than the central distribution.

idScenario	desScenario	Total distance	Mean fill rate
401	CENTRAL	2'131'000	11%
402	REGIONAL	2'393'500	13%

Figure 71: Operational KPI in LL4.

From the economical point of view, the transportation cost is lower in the regional distribution strategy. But the handling cost and the storage cost are higher in the second scenario. In total cost the second scenario is slightly higher than the first scenario.

idScenario	desScenario	Transport Cost	Handling Cost	Storage Cost	Total costs
401	CENTRAL	8'418.00 €	2'173.00 €	4'833.00 €	15'425.00 €
402	REGIONAL	4'997.00 €	3'908.00 €	7'256.00 €	16'161.00 €

Figure 72: Economical KPI in LL4.

Regarding the C02 emissions the second scenario has also a higher rate than the first one. It is about a 10% higher.

idScenario	desScenario	Total CO2
401	CENTRAL	1'065'500
402	REGIONAL	1'196'750

Figure 73: Environmental KPI in LL4.